

**ASSESSMENT OF PHYSICOCHEMICAL AND FUNCTIONAL
PROPERTIES OF FIBRE-RICH FRACTIONS OF YELLOW PEA AND
RED LENTIL TO USE IN LOW-FAT PORK BOLOGNA**

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ABSTRACT

The overall goal of this project was to investigate physicochemical and functional properties of fibre fractions from yellow pea and red lentil, as well as their application in low-fat pork bologna. The effects of lab-scale hydrothermal treatment (HT) were also investigated. This project was divided into three studies. In study 1, chemical composition and functional properties of pea and lentil fibre fractions and two commercial products, Best Pea Fibre and Superb Soy Fibre, were analyzed. Pea fibre fractions showed lighter, less red and yellow colour ($p<0.05$) than lentil fibre fractions. Due to cotyledon contamination, lentil fibre fractions contained larger amounts of protein, starch, phenolics and less dietary fibre ($p<0.05$) than pea fibre fractions. Pea fibre concentrate had more fibre, and less protein, fat and starch ($p<0.05$) than pea bran while no significant differences were found between lentil fibre fractions. All fibre products mainly consisted of insoluble dietary fibre rather than soluble dietary fibre. Only a low amount of oligosaccharides and fat were found in the fibre products. Two commercial fibre products had finer particles than pea and lentil fibre fractions. Best Pea Fibre contained similar chemical components with pea bran while Superb Soy Fibre was a protein and starch based product. For functional properties, Superb Soy Fibre, Best Pea Fibre and pea fibre fractions showed higher ($p<0.05$) water holding capacity (WHC) than lentil fibre fractions. The highest oil absorption capacity (OAC) was obtained by Superb Soy Fibre, followed by Best Pea Fibre and then pea fibre concentrate. All fibre products had higher hot absorption (HA) than their corresponding WHC except for Superb Soy Fibre. The pasting properties of all fibre products were determined by their chemical composition. Lab-scale HT effectively reduced ($p<0.05$) moisture content, but ineffectively inactivated lipoxigenase activity, and removed part of the seed coats of lentil fibre concentrate. In study 2 and study 3, HT pea and lentil fibre fractions were used to produce low-fat pork bologna (10% fat) at two levels (1.25% and 2.5%). Their effects on physicochemical, functional, textural and sensory traits were evaluated. Both fibre fractions increased ($p<0.05$) the yellowness of bologna. HT lentil fibre fractions decreased the lightness ($p<0.05$). Bologna with HT pea and lentil fibre fractions had very low cook loss and reduced purge loss but HT pea fibre fractions increased ($p<0.05$) the expressible moisture content. Bologna made with HT pea fibre fractions had soft and less cohesive texture. However, these negative effects were not found in most products containing HT lentil fibre fractions. Less juiciness, more graininess and foreign flavor ($p<0.05$) were found in bologna with fibre products during sensory evaluation without any

changes in overall flavor intensity. Best Pea Fibre did not significantly affect the functional properties of bologna while Superb Soy Fibre could improve them. They both significantly improved the textural properties of bologna ($p<0.05$). All the products except for the ones with 2.5% HT pea fibre fractions were evaluated as acceptable low-fat bologna products, providing up to 2% dietary fibre.

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LIST OF ABBREVIATIONS

a^*	Redness
AACC	American Association of Cereal Chemists
AOCS	American Oil Chemist's Society
AGT	Alliance Grain Traders
b^*	Yellowness
CIE	International commission on illumination
CFIA	Canadian Food Inspection Agency
cP	Centipoise
g	Gravitational force
HA	Hot absorption
HT	Hydrothermally treatment/hydrothermally treated
IDF	Insoluble dietary fibre
L^*	Lightness
LOX	Lipoxygenase
OAC	Oil absorption capacity
TDF	Total dietary fibre
TPA	Textural profile analysis
SDF	Soluble dietary fibre
SD	Standard deviation
SPSS	Statistical product and service solutions
STPP	Sodium tripolyphosphate
WHC	Water holding capacity
p	Probability
r	Correlation coefficient
RVA	Rapid visco analyzer
v	Volume

1. INTRODUCTION

1.1 Overview

Pulses are non-oilseed legumes which include lentil, beans, chickpea, pea and faba bean. They are grown in large amounts over large geographic areas in Canada, including Manitoba, Saskatchewan and Alberta (Pulse Canada, 2014). Inclusion of pulses in daily diet has been recommended due to their abundance in protein, starch, dietary fibre, certain minerals and vitamins (Boye et al., 2010; Roy et al., 2010). Dietary fibres have gained renewed attention from both food scientists and manufacturers mainly because of their health benefits such as facilitating bowel function, and prevention of coronary heart diseases, diabetes and obesity (Anderson et al., 2009; Stephen et al., 1980). The total dietary fibre content of pulses ranges from 14 to 32 g/100g (Tosh et al., 2010). The outer layer of grains which is referred to as the bran or seed coat is rich in dietary fibres. However, the seed coat is usually separated during early stages of processing of many pulses and discarded as waste that has no value for the food industry. Considering the chemical composition and the underutilized nature of the material, research on the seed coats of pulses should be expanded, especially for better utilization as a source of dietary fibres.

Hydrothermal treatment is a common method used in the food industry to reduce the microbial load or to enhance certain functional properties of food ingredients, such as water holding capacity and oil absorption ability. Generally, these changes in functionalities result from protein denaturation and starch gelatinization induced by heat (Huang et al., 2016; Ma et al., 2011). In addition, its impacts on pectin and resistant starch, two components of dietary fibres, were also reported (Canet et al., 2005; Chung et al., 2009; Tovar et al., 1996).

Meat and processed meat products are excellent sources of proteins, essential fatty acids, oil soluble vitamins and minerals. However, their high fat content (20 - 30%) has been linked with many chronic diseases, such as obesity, cardiovascular diseases and other disorders (Betancur-Ancona et al., 2013). Low-fat food product development, especially when using water to partially replace the fat, resulted in soft texture, low cook yield and changes in colour and flavor (Kaack et al., 2005). Therefore, various protein and starch based ingredients were incorporated

into meat products to overcome these problems (Claus et al., 1991; Pietrasik et al., 2012). Recently, because of the nutritional and functional benefits, dietary fibres from different sources were tested to improve the quality of low-fat meat products (Pietrasik et al., 2010).

The goal of this research is to investigate the physicochemical and functional properties of fibre fractions separated from yellow pea and red lentil. In addition, the effects of lab-scale hydrothermal treatment (HT) were also analyzed. The HT fibre fractions were later used to produce low-fat meat products and their effects on the physical, textural, functional and sensory properties of the final products were evaluated. The research was divided into three studies. In study 1, two fibre fractions (brans and fibre concentrates) were separated from two pulses (yellow pea and red lentil) and subjected to lab-scale HT. Their physicochemical and functional properties were investigated and verified for any effects brought by HT. In the studies 2 and 3, HT fibre fractions of yellow pea and red lentil were incorporated into low-fat pork bologna, respectively. The physicochemical, functional, textural and sensory properties of the final products were analyzed.

1.2 Hypotheses

The following hypotheses were tested to support the project goal:

1. The fibre fractions of two sources of pulses, namely yellow pea and red lentil, have different functional properties.
2. The lab-scale hydrothermal treatment (HT) will improve the functional properties of above mentioned two fibre fractions.
3. Inclusion of HT fibre fractions in the formulation will improve the functional, textural and sensory properties of low-fat pork bologna.

1.3 Objectives

1. To investigate whether yellow pea and lentil fibre fractions have different chemical characteristics and functional properties.
2. To investigate whether lab-scale hydrothermal treatment would change functional properties and chemical characteristics of lentil and pea fibre fractions.
3. To incorporate HT fibre fractions into low-fat pork bologna and investigate their effects on the functional, textural and sensory properties of final products.

2. LITERATURE REVIEW

2.1 Pulses

2.1.1 Brief introduction of pulses

Legumes are dicotyledonous seeds of plants and include 16,000 - 19,000 species in around 750 genera (Hoover et al., 1991). Legumes could fix atmospheric nitrogen for their use. Therefore, planting legume could reduce the use of nitrogen fertilizers and thus decrease environment contamination (Carrouee et al., 2002). Pulses refer to non-oilseed legumes, including lentil, beans, chickpea, pea and faba bean. Canada accounts for around 35% of global pulse trade and is the largest exporter of pea and lentil to the global marketplace (Pulse Canada, 2016c). The major Canadian-grown pulses are listed in Table 2-1. Saskatchewan is the largest producer of peas, lentils and chickpeas (Pulse Canada, 2016a).

Table 2-1 Major Canadian-grown pulses: classification, alternate names and market classes

Common name	Alternate name (s)	Genus and species	Main market classes
Beans, dry		<i>Phaseolus vulgaris</i>	Navy (white pea bean) Pinto Black Cranberry Dark red kidney Light red kidney Great Northern Small red Pink
Chickpea	Garbanzo bean (US) Bengal gram (India)	<i>Vigna angularis</i> <i>Cicer arietinum</i>	Azuki Kabuli
Lentil	Dahl (India)	<i>Lens culinaris</i>	Desi Green Red
Peas, dry	Field pea	<i>Pisum sativum</i>	Yellow Green

Modified from Tosh and Yada (2010)

2.1.2 Chemical composition of pulses

2.1.2.1 Major nutrients

Generally, pulses play a significant role in human nutrition since they are abundant in protein, dietary fibre, starch, certain minerals and vitamins but low in fat (Siddiq et al., 2012). The main chemical components of pea and lentil and their corresponding contents are shown in Table 2-2. For micronutrients, potassium is the most prominent mineral in pulses, followed by phosphorus, magnesium and calcium. Traces of copper, iron and zinc are also detected in pulses and their quantities differ with varieties and regions (Cabrera et al., 2003; Iqbal et al., 2006). Pulses are also rich in folate. Consuming pulses is especially important for the health of the elderly because it was reported to positively affect several chronic diseases and cognitive function (Rampersaud et al., 2003). Consumption of ½ cup of cooked lentil, chickpea or beans provides 115 – 180 µg dietary folate equivalents (Sutor et al., 2000).

Table 2-2 Proximate content of main chemical components of pea and lentil

Component (% dry matter)	Pea	Lentil
Protein	22.9 – 24.5	25.3 – 29.2
Starch	45.7 – 49.5	46.0 – 49.7
Fat	1.0 – 1.7	1.0 – 1.3
Ash	2.5 – 2.7	2.5 – 2.8
Dietary fibre	14.3 – 16.8	13.1 – 14.7
<i>Insoluble dietary fibre</i>	12.8 – 15.0	11.4 – 12.8
<i>Soluble dietary fibre</i>	1.5 – 1.9	1.52 – 2.0

Data modified from Wang et al. (2008), Wang et al. (2009) and Wang et al. (2004)

2.1.2.2 Dietary fibre

According to American Association of Cereal Chemists (AACC), the dietary fibre (DF) is defined as “the edible parts of plant or analogous carbohydrates that are resistant to digestion and absorption in human small intestine with complete or partial fermentation in the large intestine” (Dhingra et al., 2012). Dietary fibre is a heterogeneous complex and generally classified into soluble dietary fiber (SDF) and insoluble dietary fibre (IDF) according to their solubility. IDF includes the structural components such as cellulose, hemicellulose and lignin while SDF consists of pectin, some hemicelluloses, β-glucan, gums and mucilage (Elleuch et al., 2011). Recently, certain oligosaccharides with degree of polymerization 3-9, such as raffinose family,

and resistant starch are categorized as SDF and IDF, respectively (Tosh & Yada, 2010) due to the fact that they resist digestion and can be fermented by the colonic microbiota (Dai et al.; Guiné et al., 2016; Jones, 2014). However, their inclusion as DF is still under debate.

Dietary fibre is valued as an essential part in the human diet due to its recognized physiological effects, such as increasing stool bulk and improving laxation, lowering low-density lipoprotein cholesterol level, reducing blood glucose concentration and improving insulin sensitivity, and supporting the growth of colonic microflora by fermentation (Gunness et al., 2010; Health Canada, 2012; Li et al., 2010). Therefore, sufficient intake of DF would benefit people suffering obesity, diabetes and cardiovascular diseases. The recommended daily intake of DF is about 38 g for a man and 25 g for a woman (Institute Of Medicine, 2005). However, most Canadians only get half amount of the dietary fibre they need every day (Dietitians of Canada, 2016). Therefore, consumption of fibre-rich foods such as pulse and dietary fibre enrichment of food products is necessary to consumers and could be a new opportunity and challenge for food manufacturers.

Foods differ in the type and quantity of dietary fibres. Dietary fibres of cereals and legumes are composed of cellulose, pectin, hemicellulose, β -glucan and resistant starch. In contrast, fruits and vegetable fibres contain higher proportion of SDF such as pectin (Dodevska et al., 2013; Macagnan et al., 2015; Nieto Calvache et al., 2016; Tosh & Yada, 2010). For pulses, the total DF content ranges from 14 to 32 g/100 g, in which the IDF accounts for 10-28 g/100 g and SDF contributes 2-9 g/100 g (Tosh & Yada, 2010). Plant cell wall materials, including cellulose, hemicellulose and pectin, account for the majority of dietary fibre in both cotyledon and seed coat of pulses. More pectin is found in cotyledon fibre than seed coat fibre. Brummer et al. (2015) analyzed the cotyledon dietary fibre of cooked beans, lentil, pea and chickpea. They reported that their IDF predominantly consisted of cellulose while SDF was rich in pectin and hemicellulose. Similar composition was also found in seed coats of pulse by analyzing sugar composition of dietary fibre (Dalgetty et al., 2003; Ralet et al., 1993). Dehulling significantly reduced the crude fibre content of red lentil, meaning that more DF is present in the seed coat than the cotyledon (Wang, 2008). Dalgetty and Baik (2003) also confirmed that hulls contributed a significant portion of IDF in pea, lentil and chickpea. From the perspective of manufacturers, producing DF from seed coats is easier and less expensive due to the higher yield of fibre and less protein and starch contamination. Cotyledon fibre is usually isolated by wet fractionation

or/and enzyme digestion to obtain higher purity while seed coat fibre could achieve higher fibre yield only by milling (Dalgetty & Baik, 2003). Currently, pea hull fibre is the most well studied pulse fibre and permitted by Canadian Food Inspection Agency to use in unstandardized foods in Canada. According to Ralet et al. (1993), the total DF of pea hull is 91.5% (d.w.), including 87.4% IDF and 4.1% SDF. A fibre-rich ingredient from soybean such as Superb (Archer Daniels Midland Company, Decatur, IL, USA) is also available in the marketplace. However, the development and utilization of fibre products from other varieties of pulse crops such as lentils are still limited and need to be explored.

2.1.2.3 Phenolic compounds

Phenolic compounds are the secondary metabolites in plants. Their structures include an aromatic ring connected with at least one hydroxyl group. The main phenolic compounds found in pulses are condensed tannins, phenolic acids and flavonoids (Shahidi et al., 2003). Generally, legume seeds with dark colours have higher polyphenolic content than the seeds with light or pale colours (Campos-Vega et al., 2010). Xu et al. (2007) employed different solvents to extract phenolics from various legumes and their results showed that dark seeds such as lentil, black soybean, red kidney and black bean had much higher total phenolic content than light seeds such as yellow and green peas, chickpea and yellow soybean. Additionally, the phenolic compounds found in cotyledons and seed coats of pulse are distinct. Phenolic acids are located mainly in the cotyledon while flavonoids and condensed tannins are mostly identified in the seed coat. It was reported that seed coats of lentil and pea were rich in proanthocyanidins, catechins, glycosides of quercetin, myricetin, luteolin and apigenin, while their cotyledons contained mainly hydroxybenzoic and hydroxycinnamic acids in low concentration (Dueñas et al., 2004; Dueñas et al., 2002; Dueñas et al., 2003). Proanthocyanidins have been isolated from hulls of various beans (Hussein et al., 1990; Longstaff et al., 1993) and they were also found in seeds of coloured pea cultivars (Troszynska et al., 2002). Besides the different phenolic constituents, the seed coat usually has larger amount of phenolic compounds than the cotyledon. The acetone extracts (70% v/v) from hulls of yellow pea and green and red lentil contained more total phenolics than those extracted from the corresponding whole seed and residue (Oomah et al., 2011). Phenolic compounds have been widely recognized as antioxidants mainly for their capability to scavenge free radicals (Shahidi et al., 2015). Different phenolic constituents and concentration in

cotyledon and seed coat lead to their different antioxidant activities (Dueñas et al., 2006). High antioxidant activities of the extracts obtained from seed coats of various pulse were reported by several papers (Gujral et al., 2013; Marathe et al., 2011; Oomah et al., 2011).

2.1.2.4 Anti-nutritional factors

Even though legume seeds contain considerable amounts of proteins, carbohydrates, certain minerals and vitamins, they still have some limitations when incorporated into foods due to the presence of anti-nutritional factors, such as enzyme inhibitors, lectin, phytate, saponin and oligosaccharides (Khattab et al., 2009). These anti-nutritional factors are mostly plant secondary metabolites with high bioactivity. Specifically, enzyme inhibitors, mainly the proteinase inhibitors and α -amylase inhibitors, can impede the digestion of protein and starch (Grant et al., 1995; Leterme et al., 1992). Lectins are proteins which can bind sugars and agglutinate red blood cells (John et al., 2013). Phytate is the main phosphate reserve in pulse seed. It can combine with minerals, proteins and carbohydrates to form complexes and affect their bioavailability in the human body (Muzquiz et al., 2012). Saponins refer to a group of diverse compounds. Some of them are considered toxic for their hemolytic activity (Shi et al., 2004). Tannins could bind enzymes and therefore prevent the digestion and utilization of certain nutrients, especially protein, in pulses (Mupangwa et al., 2000). Another anti-nutritional factor present in pulse plant is α -galactoside. An important group of α -galactosides is the raffinose family which mainly comprises raffinose, stachyose and verbascose (Dey, 1980). They cannot be digested in small intestine but can be fermented by microflora in the colon causing flatulence (Gulewicz et al., 2000). Due to these harmful effects, people try to eliminate these anti-nutritional factors by different treatments (Deshpande et al., 1982; Hefnawy, 2011; Kadlec et al., 2006; Pedrosa et al., 2012). However, more and more research has shown that these anti-nutritional factors actually have some positive effects. For example, tannins, as phenolic compounds, are considered to be anticarcinogenic (Chung et al., 1998). Legume protease inhibitor could prevent the adverse effects induced by proteases in milk products (Richards et al., 2014). α -galactosides have been recently recognized as one kind of dietary fibre and could stimulate the growth of certain colonic bacteria. Gulewicz et al. (2002) observed that α -galactosides extracted from lupin and pea increased the amount of bifidobacteria in rat colon. It was reported that lentil seeds contained 0.40 g raffinose, 1.81 g stachyose and 0.48 g verbascose/ 100 g dry weight (Hefnawy, 2011).

Different varieties of lentil contained trypsin inhibitor activity, phytic acid and tannins in the range of 1.91 – 2.77 g, 6.2 – 8.8 g and 3.4 – 6.1 g/kg dry matter, respectively (Wang et al., 2009). They also reported that the trypsin inhibitor activity and phytic acid in different varieties of peas were in the range of 1.30 – 2.01 and 6.4 – 8.3 g/kg dry matter, respectively (Wang et al., 2008).

2.1.2.5 Lipoxygenase

Lipoxygenase (LOX) is an oxidative enzyme and present in various plants and animals. It catalyzes the oxidation of polyunsaturated fatty acids with *cis,cis*-1,4-pentadiene structure into corresponding hydroperoxides (Baysal et al., 2007). Chang et al. (1985) investigated the LOX activity of fourteen legumes and observed that soybean, cowpea and lentil had the highest LOX activity while chickpea, lima bean and mung bean showed the lowest LOX activity. Stephany et al. (2015) showed that different lupin species had significant variations in their LOX activity. Eriksson (1967) analyzed the LOX distribution in different parts of green pea. Their results indicated that around 80% of lipoxygenase was found in the outer part of cotyledon, 12% in the inner part of cotyledon and 5-8% in the skin part. For food application, even though LOX could be applied into breadmaking for its positive effects on colour and texture (Junqueira et al., 2008; Zhang et al., 2013), in most cases its presence in food products rich in unsaturated fatty acids causes quality deterioration. For example, LOX is responsible for the production of off-flavor, loss of certain pigments and essential fatty acids (Klein et al., 1985; Robinson et al., 1995). The grassy, beany taste in soybean was mainly attributed to the lipid oxidation caused by LOX (Dahuja et al., 2003). LOX also acts as enzymatic initiator to start lipid peroxidation in some meat products (Min et al., 2005). All the changes make food products less acceptable and less nutritional. Therefore, some treatments are employed to reduce its activity, especially heat treatment. Pressurization and subsequent water blanching significantly eliminated the LOX activity in green beans and green peas (Akyol et al., 2006). Infrared treatment effectively reduced LOX activity in soybeans and increased infrared power and longer treatment time had better effects (Yalcin et al., 2015). Particularly, some antioxidants such as phenolics are effective in inhibiting LOX activity. Flavonoids were reported to achieve at least 10% inhibition of soybean LOX activity (King et al., 1987).

2.2 Physicochemical and functional properties of dietary fibre

Dietary fibres from different sources possess distinct metabolic and physiological functions. These functions are usually determined by their physicochemical properties and their fate through the digestive tract (Guillon et al., 2000).

2.2.1 Hydration

Hydration is one of the most important properties of dietary fibres which is highly associated with their application in food products. It affects the performance of dietary fibre in the digestive tract and is responsible for some physiological effects such as fecal bulking (Dhingra et al., 2012). The hydration capacity also accounts for the increased viscosity and improved water holding capacity of food products with dietary fibres (Dikeman et al., 2006). The hydration properties of fibres could be characterized by water absorption, water holding capacity and swelling (Elleuch et al., 2011). The factors determining the hydration capacity of DF include their chemical composition, structural characteristics, processing history and the surrounding chemical environment (Tosh & Yada, 2010). The hydration ability of DF is also significantly related to its source. Fibre concentrates extracted from fruits and vegetables showed higher affinity for water than those from cereals such as wheat and oat bran (Grigelmo-Miguel et al., 1999). Sosulski et al. (1982) measured the water hydration capacity of dietary fibres from different sources and they reported that higher values were obtained by fibres rich in mucilage and pectin, such as psyllium seeds, flax hulls, mustard hulls and sunflower heads, and lower values were obtained for fibres rich in cellulose such as pea hulls. In addition, changing the particle sizes of dietary fibres will change their hydration capacity. On the one hand, reducing the particle size could increase the surface area and expose more polar groups and water-binding sites to interact with the surrounding water. On the other hand, reducing particle size will destroy the porous matrix structure to some extent which is responsible for holding large amounts of water through the hydrogen bonds and capillary forces (López et al., 1996; Zhu et al., 2015). Therefore, the resulting hydration capacity of dietary fibre will be determined by both effects brought by changing particle size. Raghavendra et al. (2006) found that reducing the particle size of coconut dietary fibre to 550 µm increased its hydration properties. However, further grinding would significantly reduce these properties. López et al. (1996) reported that reducing the particle size of dietary fibre by cellulase increased the water binding capacity of insoluble dietary

fibre and decreased the value of soluble dietary fibre. They assumed that the physical structure was important to the hydration property of insoluble dietary fibre. Auffret et al. (1994) proved that this effect was fibre-specific. They found grinding reduced the swelling capacity and water-binding capacity of wheat bran, sugar-beet and citrus fibre. They speculated that this reduction resulted from the fibre matrix collapse after grinding. However, they found improved hydration ability in ground pea hull. The possible explanation they provided was that its microcrystalline cellulose structure prevented the destruction from grinding and the increased surface area and pore volume favored the hydration ability. Other factors, such as surrounding environment (pH, temperature, type of ions in solution) also exert effects on their hydration properties (Elleuch et al., 2011). Wang et al. (2011) measured the water hydration capacity, swelling capacity and water retention capacity of fibre fractions of pea and lentil cotyledons with values of 4.4 g/g, 17.7 – 19.2 mL/g and 8.5 – 8.8 g/g dry matter, respectively, for peas and 5.0 – 5.7 g/g, 22.7 – 27.0 mL/g and 8.9 – 11.4 g/g dry matter, respectively for lentils. They speculated that the hydration capacity was determined by the level of pectin and IDF in fibres and by their particle size and specific surface area. Dalgetty and Baik (2003) found that water holding capacity of pulse cotyledon IDF was higher than hull fibres.

2.2.2 Oil absorption capacity

Oil absorption capacity is defined as the amount of oil a certain amount of dietary fibres can retain. From the physiological perspective, the dietary fibre with high oil absorption capacity could absorb or bind bile acids and increase their excretion which is associated with plasma cholesterol reduction (Tosh & Yada, 2010). In food application, it can prevent the loss of fat or oil during cooking and therefore increase the cook yield and improve the texture and flavor of final products. The oil absorption capacity of dietary fibres is mostly determined by their structural features and surface properties, and also affected by hydrophobic groups and overall charge density of constituents (Biswas et al., 2011; Elleuch et al., 2011). It was reported by Wang and Toews (2011) that the fat absorption of pea and lentil cotyledon fibres were in the range of 1.63 – 1.95 g/g and 1.10 – 1.12 g/g dry matter, respectively. They also observed significant correlations between the fat absorption and the specific surface area and mean particle size of dietary fibres. Raghavendra et al. (2006) reported that grinding coconut fibres increased their fat absorption capacity due to the increased physical structure and surface area. Furthermore, lignin

is a good adsorbent for dietary oils (Tolba et al., 2011). It was reported that the fibre source rich in lignin such as sunflower hull showed very high fat absorption (Sosulski & Cadden, 1982). Lignin-reduced soy hulls could absorb 53% more water than crude soy hulls (Muzilla et al., 1989). Cotyledon IDFs from peas, lentils and chickpeas were reported to have better oil binding capacity than hull fibres and cotyledon SDFs (Dalgetty & Baik, 2003).

2.2.2.1 Particle size

Particle size is an important property of dietary fibres which influences their functionality and physiological performance in the digestive tract. These changes mostly occur through the altered surface area characteristics. On one hand, the water holding capacity and oil absorption capacity can be affected by the surface area characteristics, porosity and exposed polar or non-polar groups of dietary fibres. On the other hand, the available surface can impact the utilization of dietary fibres by colonic microflora (Dhingra et al., 2012). Huang et al. (2008) reported that micronized insoluble dietary fibre from starfruit pomace treated by jet mill and high-pressure micro-sizer could increase the faecal output and moisture retention in faeces. They assumed that the treatment possibly broke down the fibre structure and exposed more surface area. These changes would benefit the bacterial growth and improve the water-holding capacity of dietary fibres. Dehority et al. (1961) has proved that reducing the forage particle size physically by ball-milling increased the cellulose digestion. The particle size of dietary fibres is mainly determined by their origin and processing history. Another thing should be taken into consideration is that the particle size of dietary fibre will change after chewing, stomach grinding, and degradation and digestion by intestinal microflora (Tosh & Yada, 2010). Therefore, it is difficult to speculate their performance on transit time based on their initial particle size (Guillon & Champ, 2000).

2.3 Hydrothermal treatments of pulse flours

Heat treatment is an essential procedure employed in the food industry for killing harmful microorganisms and inactivating deleterious enzymes (Akyol et al., 2006; Silva et al., 2012). In some cases, it also could be utilized to destroy thermo-labile anti-nutritional factors and modify the functional properties of pulse products by changing the physicochemical properties of proteins, starches, and sometimes, dietary fibres (Ma et al., 2011). The temperature, treatment time and water presence are three important factors to optimize during heat treatment, especially

the presence of water. Heat treatment can be classified into dry heat treatment and hydrothermal treatment, based on whether water or steam is present (Bucsell et al., 2016). Hydrothermal treatment is also referred to as heat-moisture treatment. Flour functionalities are more likely to be modified by this process due to changes in the structure of certain constituents such as protein and starch (Wood, 2016).

2.3.1 Effects of hydrothermal treatment on protein and starch

Protein denaturation and starch gelatinization are two main changes that usually occur under hydrothermal treatment (Arns et al., 2015; Ma et al., 2011). These changes in structure ultimately influence their functional properties. For proteins, heat treatment could modify the secondary, tertiary or quaternary structure without breaking any covalent bonds. The resulting functionality will be determined by the nature and type of the proteins as well as the degree of denaturation (Wu et al., 1974). Slight protein denaturation could benefit its functional properties, but extensive denaturation will be detrimental due to changed surface properties (Aguilera et al., 2009). Heat treated velvet bean flours showed better water-holding capacity and oil-binding ability than untreated ones. These changes were attributed to the increased water-binding sites and non-polar residues exposed by the denatured proteins (Ahenkora et al., 1999). Heating at 90 °C for 5 min dramatically increased the surface hydrophobicity of pea protein fractions by unfolding the protein molecules and exposing buried hydrophobic regions (Koyoro et al., 1987). Starch is an abundant constituent in pulse seeds. It will undergo gelatinization upon heating at the presence of water, inducing the granule swelling, water uptake and amylose leaching. The magnitude of these changes depends on the moisture content, heat temperature and the source of starch and its structure. Heat treatment at 100 °C for 16 h at a moisture content of 30% of native starches of pea, lentil and beans did not significantly change their granule size and shape but restricted their swelling capacity and amylose leaching (Hoover et al., 1996). The gelatinization characteristics such as the gelatinization temperature of the pulse starch could also be altered after hydrothermal treatment and different treatments led to different degree of changes (Chung et al., 2009, 2010). Compared with the whole seed, pulse flours more easily underwent cross-linkage of protein and starch when boiled severely (90°C for 20 min) with large amounts of water (flour to water, 10% w/v) for the reason that the two components were well exposed and intimately mixed (Ma et al., 2011).

2.3.2 Effects of hydrothermal treatment on dietary fibre

Hydrothermal treatment could bring some changes to dietary fibres of pulses (Canet et al., 2005; Johnson et al., 2015; Svanberg et al., 1997). Their structure could be modified or disrupted during the treatment, leading to changes in their molecular weight and structure characteristics, which probably will change their physicochemical properties and therefore affect their application in the food products. The main constituents of dietary fibres affected by heat treatment are resistant starch and pectin. Legumes, with more amylose in their starch compared with other crops, are more likely to undergo retrogradation after heat treatment, resulting in increased resistant starch content (Perez-Hidalgo et al., 1997). Significant increase in the resistant starch concentration was observed in lentils when they were subjected to cooking (boiling for 40 min) and subsequent cooling. The possible explanation provided for this increase was the formation of retrograded starch (type 3 resistant starch) (Johnson et al., 2015). Regarding the other fibre constituents, heat treatment could boost the solubility of the pectin by degrading the galacturonate chains. Blanching green beans at 85, 90 and 97 °C was shown to break down pectic polymers and impair the firmness of cell walls (Canet et al., 2005). Extensive microwave (4+3×2 min, 700 W) heat treatment reduced total dietary fibre content due to the breakdown of pectic polysaccharides (Svanberg et al., 1997). The proportions of IDF and SDF in the total dietary fibres content are important for their physiological functions. However, the effects of hydrothermal treatment on them are not consistent. Soaking and then cooking lentils and peas increased their IDF but decreased the SDF (Wang et al., 2008; Wang et al., 2009). This possibly resulted from the softening of SDF and formation of protein-fibre complex as IDF. Perez-Hidalgo et al. (1997) measured the nitrogen content in the IDF of raw chickpeas and boiled chickpeas. They found there was an increase in nitrogen content from 9% to 14%, demonstrating that the products of Maillard reaction may contribute to the increase in IDF. Changes brought by the hydrothermal treatment in dietary fibres are complicated and different, depending on the sources of dietary fibres, treatment method and treatment time (Chang et al., 1990; Kutoš et al., 2003).

2.3.3 Effects of hydrothermal treatment on anti-nutritional factors

Hydrothermal treatment is also used to destroy certain anti-nutritional factors of pulses, such as enzyme inhibitors, lectins and α -galactosides, because these factors are susceptible to

high temperature. Also, most of the compounds are water soluble and can be removed with the cooking water (Akande et al., 2010). The trypsin inhibitor activity of lentil, chickpea and pea flours was significantly reduced by hydrothermal treatment (boiling in water bath at 90 °C for 20 min) (Ma et al., 2011). Amylase inhibitors of faba bean, cowpea, lentils and chickpea were effectively inactivated by blanching (boiling for 10 and 30 min) and cooking (cooking in water until being soft) (Shekib et al., 1988). Cooking beans, chickpeas, lentils and peas in boiling water reduced their oligosaccharide content (raffinose, stachyose and verbascose) (Wang et al., 2008; Wang et al., 2009; Wang et al., 2010). Reduction in anti-nutritional factors could improve the utilization of other nutrients in pulses such as the protein and starch, and prevent the flatus production caused by α -galactosides.

2.4 Application of dietary fibre in processed meat products

2.4.1 Processed meat products

Processed meat is a very broad category of products including bacon, ham, sausages, bologna, meat patties and meat balls and so on (Santarelli et al., 2008). These products are produced through one or more procedures such as grinding or chopping, adding non-meat ingredients such as salt and nitrite, cooking and other treatments. Processed meat products usually have better texture, appearance or flavor and improved shelf life and functionality compared with fresh meat (Forrest et al., 1975). Bologna is a typical processed meat product and formulated based on an emulsion system. Emulsion type meat products have a biphasic system including fat globules as the dispersed phase and a salt solution with solubilized myofibrillar proteins extracted from meat as the continuous phase. The fat particles are coated with soluble protein and dispersed in the matrix. Meat emulsions are not true emulsion systems because of the much larger fat droplet size and the presence of insoluble proteins, connective tissue, meat particles, and other materials in the continuous phase (Ugalde-Benítez, 2012).

Several ingredients are used to form bologna. Meat fat, protein and water are the basics for bologna products. Salt is another important ingredient to form meat emulsion system because it solubilizes the functional meat myofibrillar proteins, which act as the emulsifier to coat the fat granule and are also responsible for binding water (Sofos, 1983). Adding large amounts of extra water will decrease the ionic strength of meat batters and therefore reduce the protein extraction, resulting in unfavorable texture. However, excessive protein extraction by high ionic strength of

meat batters also leads to tough skin and rubbery texture (Schmidt, 1984). Sodium tripolyphosphate is usually added to bologna products to improve their water holding capacity by changing the net charge of meat protein (Forrest et al., 1975). Nitrite contributes to the formation of reddish-pink colour of cured meat products and brings positive influences on their flavor and safety as well (Bedale et al., 2016).

2.4.2 Low-fat processed meat products

Meat is an excellent source of proteins, essential fatty acids, oil soluble vitamins and minerals (De Smet et al., 2016). Animal fat is an important constituent of meat products because it contributes to their appearance, texture, mouth feel, flavor, juiciness and storage stability (Barbut, 2011; Shand, 1997). However, the higher fat content (20 - 30%) in processed meat products than fresh meat will increase the risk for several health problems such as obesity, cancer and cardiovascular diseases (Grasso et al., 2014; Keeton, 1994). According to the World Health Organization, total fat in a healthy diet should not exceed 30% of total energy intake to avoid unhealthy weight gain. Additionally, the consumption of unsaturated fats is recommended rather than saturated fats (World Health Organization, 2015). Based on these facts, meat products with reduced fat content are promoted in recent years. The amount of fat reduced in certain meat products depends on the nature of products, and also determined by how the products are formulated and what kind of processing is required. In the finely ground and emulsified meat products, such as bologna, the fat content can be as low as 10% in the finished product (Colmenero, 1996). Fat reduction can be achieved by using leaner meats or adding more water. However, changes in the flavor and texture may occur. For example, fat reduction by adding leaner meat increases the cost and results in bland and less juicy meat products with a hard and rubbery texture (Brewer, 2012; Su et al., 2000). Also, directly substituting water for fat leads to softer texture, increased cook loss and purge accumulation (Claus & Hunt, 1991; Shand, 2000). Therefore, in order to maintain or improve desirable texture and flavor, fat-reduced meat products should be carefully reformulated with selected raw meat, appropriate amounts of water, fat from animal or vegetable or crop sources, flavorings and other ingredients such as binders or fat substitutes (Jiménez-Colmenero et al., 2001).

2.4.3 Binders in processed meat products

To reduce the cook loss and production cost, and improve textural properties, nutrition and flavor, a variety of non-meat ingredients have been employed as fillers, binders and extenders in low-fat meat products (Claus & Hunt, 1991; Tahmasebi et al., 2016). The most well-known non-meat binder is plant derived starch due to its low-cost and ability to bind water, increase viscosity and improve textural characteristics (Pietrasik et al., 2012). Addition of starch is necessary especially for the products formulated with high amount of water. Carballo et al. (1995) included waxy corn starch to produce pork bologna with various fat levels and they concluded that adding more starch effectively reduced the cook loss and fluid release during storage. They assumed that starch benefited the emulsified meat products by forming stronger heat-induced structures. The swelling of starch granules embedded in the protein gel matrix during heating increased water-binding capacity and created a firmer and more compact structure. Reduced purge loss was also observed due to incorporating pea starch, potato starch and wheat starch into bologna products (Claus & Hunt, 1991; Pietrasik & Janz, 2010; Shand, 2000).

The non-meat proteins could also be used as binders or extenders in meat products because of their water and fat binding capacity, emulsifying capacity and gelling ability (Boye et al., 2010; Xiong, 2012). Soy protein isolate was used to produce pork sausages by partially replacing the meat (Akesowan, 2008). The results showed that adding 2% soy protein isolate could achieve a product with higher cook yield, less purge loss and firmer texture. The soy protein contributed to forming protein membrane on the surface of fat globules and preventing their agglomeration. More importantly, their gelling ability and water retention capacity have a great influence on low-fat meat products (Su et al., 2000).

Besides starch and protein, dietary fibres derived from plant sources are gaining more attention for their potential application in meat products (Mehta et al., 2015). First of all, their inherent physiological benefits will attract health conscious consumers. According to Canadian Food Inspection Agency, foods containing 2 g, 4 g and 6 g dietary fibre per serving size could be claimed as source of fibre, high source of fibre and very high source of fibre, respectively. Furthermore, compared with starch and protein, dietary fibres provide lower calories because of their indigestibility. The current average energy value of dietary fibre is 2 kcal/g, which is much lower than that of carbohydrate (4 kcal/g), protein (4 kcal/g) and fat (9 kcal/g) (Health Canada, 2010). Therefore, people will intake less calories by having meat products containing dietary

fibre as binders than protein and starch. Additionally, because of the high water and fat binding capacity, dietary fibres could be used to achieve high yields. This especially benefits manufacturers who can make more profits out of the same amount of meat. Pork burgers with increased amounts of tiger nut fibre (5% - 15%) had better nutritional values and improved cooking characteristics (Sánchez-Zapata et al., 2010) such as increased cooking yield and fat and moisture retention, and less diameter reduction. They suggested that the tiger nut fibre prevented the loss of water and fat resulting from the meat protein denaturation during cooking. Pea fibres have been proved to have fat holding capacity even at high temperature. Adding 10 -16% pea fibres into high fat ground beef increased its fat retention from 33% to 85% - 98% even though it was cooked to 90 °C (Anderson et al., 2001). Besides the better cooking characteristics, improvement in some textural and sensory attributes of meat products has also been observed when adding dietary fibres. Including inner pea fibre in low fat beef patties improved their tenderness and cooking yield without negative effects on their juiciness and flavor (Anderson et al., 2000). Incorporation of 4% pea fibre (Uptake 80) into low-fat bologna (10%) significantly improved its texture properties and could even achieve a textural profile similar to the bologna with higher fat level (20%). It also improved the cooking and purge properties of low fat bologna and increased its water holding capacity without sacrificing its acceptability to consumers (Pietrasik & Janz, 2010). de Oliveira Faria et al. (2015) reported that the gels formed with pork skin, water and amorphous cellulose could partially replace the pork back-fat in bologna and resulted in products with improved emulsion stability and lower cooking loss. They suggested that amorphous cellulose fibres would interact with proteins and therefore create a more rigid gel matrix that prevented the exudation of water and fat.

The application of dietary fibres from different sources in different food products is determined mainly by their physicochemical properties, functionalities and modifications during food processing. Other factors such as the colour and flavor should also be considered to avoid any negative effects on the sensory characteristics of final products (Biswas et al., 2011). Currently, the fibre sources approved by Canadian Food Inspection Agency (Canadian Food Inspection Agency, 2017) for human consumption in unstandardized foods include barley bran, β -glucan from oat or barley, corn bran, oat bran, wheat bran, pea hull fibre, soy cotyledon and so on. Pea hull fibre is commercially available and provided by many ingredients company such as Best Cooking Pulses and AGT Food and Ingredients. It has been successfully applied to baked

products, pasta and meat products. Also, a new soy fibre product named Superb is currently available on the marketplace provided by Archer Daniels Midland. However, the analysis and application of fibre products derived from other legumes, such as lentils, need further exploration.

3. Study 1: Physicochemical and functional properties of heat treated and non-heat treated fibre fractions of yellow pea and red lentil

3.1 Abstract

In this study, physicochemical and functional properties of HT and non-HT fibre fractions of yellow pea and red lentil were analyzed. After dehulling, brans and fibre concentrates of yellow pea and red lentil were obtained by screening. A sub-sample of each was subjected to lab-scale hydrothermal treatment. Three lots of samples were analyzed. After milling, lentil fibre fractions had finer particles than pea fibre fractions. Pea fibre fractions were lighter and less red and yellow ($p<0.05$) in colour than lentil fibre fractions. For chemical characteristics, lentil fibre fractions contained more protein, starch, fat, phenolics, and less total dietary fibre ($p<0.05$) than those of pea fibre fractions due to considerable cotyledon contamination. Insoluble dietary fibre accounted for 93.20 – 95.08% of total dietary fibre of all fibre products. Pea fibre concentrate had more dietary fibre and less protein, fat and starch ($p<0.05$) than pea bran but no significant difference was found between lentil bran and lentil fibre concentrate. Only few amounts of oligosaccharides were found in all fibre products. Pea fibre fractions had higher lipoxxygenase activity (LOX) ($p<0.05$) than lentil fibre fractions. Best Pea Fibre and Super Soy Fibre showed finer particles and lower LOX activity than pea and lentil fibre fractions. Best Pea Fibre had similar chemical composition with pea bran while Superb Soy Fibre was a protein and fibre based product. For functional properties, Superb Soy Fibre, Best Pea Fibre and pea fibre fractions showed higher water holding capacity (WHC) ($p<0.05$) than lentil fibre fractions. The highest oil absorption capacity (OAC) was observed in Superb Soy Fibre, followed by Best Pea Fibre and then pea fibre concentrate. All fibre products had higher hot absorption (HA) than their corresponding WHC except the reduced value found in Superb Soy Fibre. Lentil fibre fractions showed pasting properties of starch based ingredients while pea fibre fractions and two commercial products only gradually increased in their viscosity. The viscosity measured under bologna cooking method was lower than standard method due to the lower holding temperature. HT significantly reduced the moisture content. However, it had no effects on most functional properties and LOX activity, and removed part of seed coats from lentil fibre concentrate.

3.2 Introduction

Pea and lentil are two major pulse crops grown in Canada and exported in large quantities to the global pulse market. The seed coat of pea and lentil accounts for approximately 8% of the whole seed and is regarded as the main by-product of pulse processing in Canada (Oomah et al., 2011). Dehulling is a common procedure employed to remove seed coats from seeds in order to improve their appearance and palatability, reduce the cooking time and achieve better digestion and utilization in the human body (Patil et al., 2003). However, the seed coat of pulse crops is actually a great source of dietary fibre and abundant in various phenolic compounds (Dueñas et al., 2004; Dueñas et al., 2002; Weightman et al., 1995; Weightman et al., 1994). These are two components beneficial to human health. Dietary fibre intake is linked with increasing volume of fecal bulk, shortening of intestinal transit time, lowering blood cholesterol and blood glucose levels, and supporting the growth of colonic microflora (Dhingra et al., 2012). Phenolic compounds may lower the risk of health disorders due to their antioxidant activity (Shahidi & Ambigaipalan, 2015). From the perspective of food product development, dietary fibres are functional ingredients and excellent binders of water and oil (Tosh & Yada, 2010). Based on these facts, it is worth exploring the better utilization of seed coat fractions of pea and lentil for their further application in food products or for extracting phytochemicals with economic value.

Hydrothermal treatment is predominantly used for reducing moisture content, killing the microorganisms and inactivating deleterious enzymes (Akyol et al., 2006; Albuzaudi et al., 2017). Therefore, the shelf life of the food products or ingredients can be extended. It could also induce starch gelatinization and protein denaturation to some extent, depending on the treatment time, temperature, moisture content and other factors (Adebowale et al., 2009; Odjo et al., 2012). Furthermore, certain anti-nutritional factors will be removed or inactivated by this treatment (Wang et al., 2008; Wang et al., 2009; Wang et al., 2010).

The purpose of this present study is to analyze the physicochemical and functional properties of two fibre fractions (bran and fibre concentrate) of yellow pea and red lentil. The effects of lab-scale hydrothermal treatment (HT) on the lipxygenase activity and their functional properties, such as water holding capacity, oil absorption capacity, hot absorption and pasting property, were also investigated. The results will help to determine the effectiveness of dehulling and sieving to separate fibre-concentrated products, to compare functional properties of different fibre products and to learn about the effects of HT on their enzyme activity and

functionality. The selection of some functionality tests that are directly applicable to meat products will aid in predictions of the performance of fibre products in meat products.

3.3 Materials and methods

3.3.1 Sample preparation from yellow pea and red lentil

Fibre fractions were provided by a pulse processing company (AGT Food and Ingredients, Saskatoon, SK, Canada) that were processed according to their experimental protocols. Details of the processing procedure were shown in Figure 3-1.

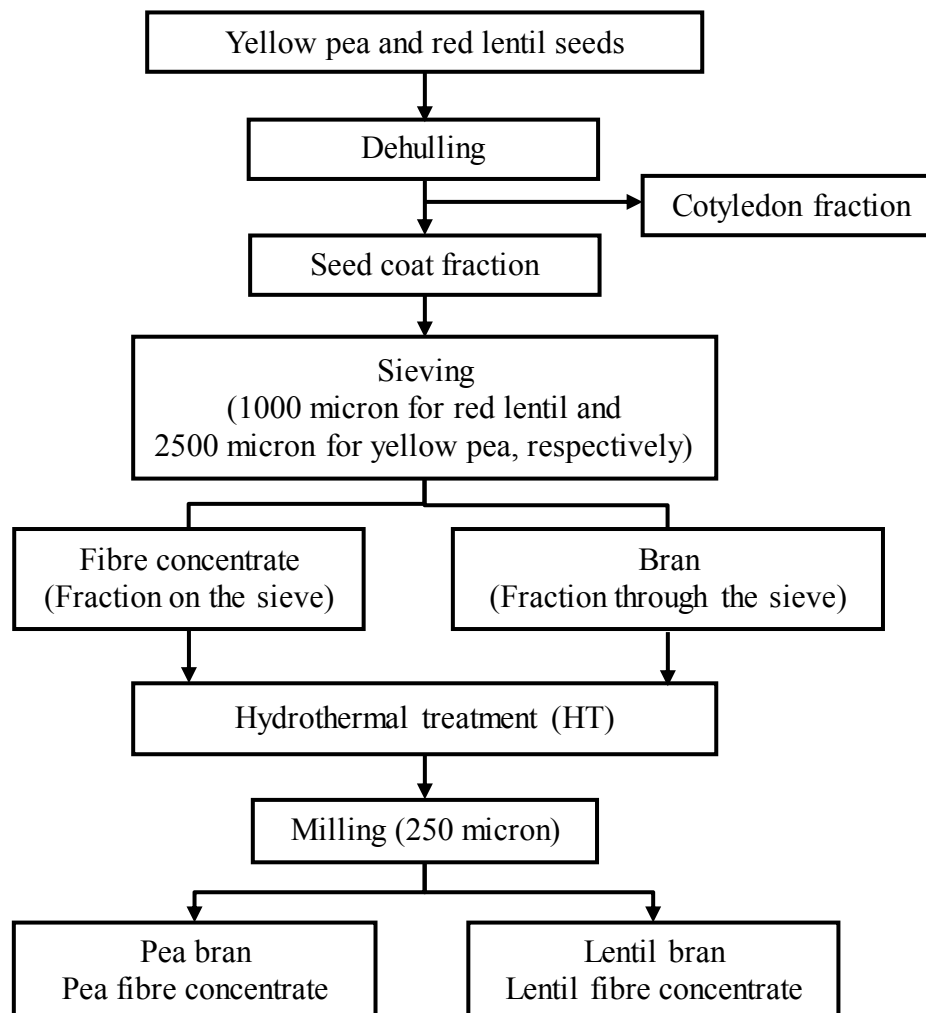


Figure 3-1 Flow chart of preparation of fibre fractions from yellow pea and red lentil

After dehulling, seed coats of yellow pea and red lentil were separated into two fibre fractions using a Vibrating Screen Separator at the Saskatchewan Food Industry Development Centre, Saskatoon, Canada. The sieve size of screening was 1000 micron and 2500 micron for red lentil and yellow pea, respectively. The portion remaining above the sieve was referred to as fibre concentrate while the portion going through the sieve was called bran. After that, lab-scale hydrothermal treatment (HT) was employed to treat the fibre fractions. HT was carried out in the research and development facilities at AGT Food and Ingredients and involved heating in an oven at 180 °C for 10 min with elevated relative humidity. Afterwards, all the samples were milled by an Ultra - Centrifugal Mill (Retsch, PA, USA, Model ZM 200) at Saskatoon Research and Development Centre, Agriculture and Agri-Food Canada (Saskatoon, SK, Canada). The sieve size for milling was 250 micron and the rotor speed was 12,000 rpm. Two commercial products, named Best Pea Fibre (Best Cooking Pulses Inc., Saskatoon, SK, Canada) and Superb Soy Fibre (Archer Daniels Midland Company, Decatur, IL, USA) were used as references for comparison. These two reference samples were chosen based on their chemical composition. The Best Pea Fibre is pea hull fibre with dietary fibre as the main component (Best Cooking Pulses Inc., 2017) which can be used for comparison with pea fibre fractions. The Superb Soy Fibre was soy cotyledon fibre with protein and dietary fibre as the major components (Archer Daniels Midland Company, 2017) and therefore it is a good reference for lentil fibre fractions. No commercial lentil fibre products were available at the time this study was started.

3.3.2 Physicochemical properties

a) Particle size distribution

The particle size distribution was measured by AACC Method 55-60.01 (AACC, 1999) on the fibre products received after milling. A series of sieves with different sizes (425, 250, 150, 106 and 75 micron) were arranged from top to the bottom. About 5 g of milled fibre sample was poured into the top sieve and sieved for exactly 10 min on the sieve shaker with percussion. Each sieve was weighed with the sample on it and the screen weight was subtracted to get the sample weight. The particle size distribution was determined as the weight percentage of recovered sample from each sieve.

For each sieve:

$$\text{Recovered fibre sample \%} = \frac{\text{Weight of fibre sample recovered from sieve}}{\text{Total sample weight}} \times 100 \quad (\text{eq. 3.1})$$

b) Colour measurement

The HunterLab Miniscan XE colourimeter (Hunter Associations Laboratory Inc., Reston, VA, USA, Model 45/0L) was employed to measure the colour of flours based on L*, a* and b* dimensions with illuminant A and 10 ° observer. The plastic petri dish (60 × 15 mm) was filled with the fibre sample and capped with plastic lid for measurement. Each sample was read twice with 90° rotation between the readings. All the samples were measured in duplicate.

c) Moisture

The moisture contents were determined by AOAC Method 925.10 (AOAC, 1990) with a slight modification. Two g fibre samples were dried in air oven at 100 - 102 °C overnight. The moisture content was calculated as the percentage of weight loss before and after drying.

d) Crude protein

The protein content was evaluated by AACC Method 46-30.01 (AACC, 1999), namely Combustion Method. A 30 - 60 mg fibre sample was accurately weighed and analyzed by a nitrogen analyzer (Thermo Fisher Scientific, Delft, Netherlands, Model FLASH EA 1112). The nitrogen conversion factor for legume protein was 6.25.

e) Crude fat

Crude fat content was measured by AOCS method Am 2-93 (AOCS, 1995) using Swedish tube. A 2 - 3 g flour sample was extracted by 25 ml hexane for 20 min. After filtration and solvent evaporation, the extracted oil was dried in air oven at 130 °C for 20 min and reweighed.

f) Ash

AOAC Method 923.03 (AOAC, 1990) was employed to assess the ash content. A 3 g fibre sample was charred for around 20 min and cinerated at 550 °C overnight in the muffle furnace. After cooling down, the crucible was weighed.

g) Dietary fibre (insoluble/soluble dietary fibre)

The total, soluble and insoluble dietary fibres were determined using enzymatic-gravimetric method AACC Method 32-45.01 & 32-50.01 (AACC, 1999) by Megazyme kit. Duplicate

samples of 1.000 g were digested by 40 mL of pancreatic α -amylase/amyloglucosidase mixture at 37 °C for exactly 16 h. Then, the pH of mixture was adjusted to approx. 8.2 by adding 3.0 mL of 0.75 M Tris base solution. Samples were placed in a water bath at 95-100 °C, and incubated for 20 min with occasional shaking. Then, 0.1 mL of protease solution was added with a positive displacement dispenser and the mixture was incubated at 60 °C for 30 min. Insoluble dietary fibre was obtained by filtering the enzyme digest through the crucible and soluble dietary fibre was obtained by precipitating the filtrate with 4 volumes of 95% (v/v) ethanol. Both insoluble and soluble dietary fibre were corrected by ash and protein content. The total dietary fibre, insoluble dietary fibre and soluble dietary fibre were calculated by the following equations.

$$\text{Blank (B) determination (mg)} = \frac{BR_1 + BR_2}{2} - P_B - P_A \quad (\text{eq. 3.2})$$

Where:

BR_1 and BR_2 = residue mass (mg) for duplicate blank determinations respectively.

P_B and P_A = mass (mg) of protein and ash respectively, determined on first and second blank residue.

Total dietary fibre (TDF), insoluble dietary fibre (IDF) or soluble dietary fibre (SDF) (mg/100 g)

$$\text{TDF/IDF/SDF}\% = \frac{\frac{R_1 + R_2}{2} - P_B - P_A - B}{\frac{M_1 + M_2}{2}} \times 100 \quad (\text{eq. 3.3})$$

Where:

R_1 = Residue mass 1 from M_1 in mg.

R_2 = Residue mass 2 from M_2 in mg.

M_1 = Test portion mass 1 in g; M_2 = Test portion mass 2 in g.

P_A = Ash mass from R_1 in mg; P_B = Protein mass from R_2 in mg.

TDF (%) = TDF (mg/100 g)/1000

IDF (%) = IDF (mg/100 g)/1000

SDF (%) = SDF (mg/100g)/1000

B = from eq.3.2

h) Total phenolics

The phenolic compounds were extracted with 70% (v/v) acetone (Oomah et al., 2010) and

the absorbance values were measured using a UV-Visible spectrophotometer (Oomah et al., 2005). About 200 mg of the sample was extracted with 6 mL of 70% (v/v) acetone for 2 h at room temperature for 2 times. The supernatant was combined and filtered through 0.45 μ m Nylon filter (Canadian Life Science, Edmonton, Canada). One mL (pea) or 0.5 mL (lentil) of the extract was evaporated at low temperature and redissolved in 1 mL 80% (v/v) ethanol. A 100 μ L of the solution was mixed with 150 μ L 2% (w/w) HCl in 80% (v/v) ethanol in the wells of a 96-well ultraviolet flat-bottom plate for 2 min. The absorbance of the mixture was monitored by Microplate Spectrophotometer (Bio-Rad Laboratories Ltd, Japan, Model xMark) at 280 nm, 320 nm, 360 nm and 520 nm using catechin, quercetin, caffeic acid and cyanidin-3-glucoside as the standard, respectively.

i) Total starch

The measurement of total starch content was based on AACC Method 76-13.01 (AACC, 1999) using Megazyme kit. About 100 mg sample was weighed into a polypropylene centrifuge tube and incubated with 5 mL of aqueous ethanol (80%, v/v) at 80 °C water bath for 5 min. The mixture was stirred and another 5 mL of aqueous ethanol (80% v/v) was added. After centrifugation, the supernatant was discarded and this step was repeated one more time. Two mL of dimethyl sulphoxide (DMSO) was added to the tube and mixed thoroughly by vortex mixer. The tube was placed in a vigorously boiling water bath for 5 min. Three mL of the thermostable α -amylase was added and the tube was incubated in boiling water for 12 min. The tube was stirred vigorously at 4, 8 and 12 min and then placed into the 50 °C water bath for 10 min. Then 0.1 mL of the amyloglucosidase was added to the tube. After mixing, the tube was incubated at 50 °C water bath for 30 min. The entire content of the tube was transferred to a 10 mL (for pea) or 25 or 50 mL (for lentil) volumetric flask and the tube was rinsed with distilled water. An aliquot of the solution was centrifuged for 10 min. Duplicate 0.1 mL clear solution were mixed with 3.0 mL of GOPOD Reagent to react. D-glucose control consisted of 0.1 mL of D-glucose standard solution (1 mg/mL) with 3.0 mL of GOPOD Reagent. The solution was replaced with distilled water to make the blank. The mix was incubated at 50 °C for 20 min and absorbance was read at 510 nm against the blank in 60 min. The starch content was calculated using the following equation.

$$\text{Starch \%} = \Delta A \times \frac{F}{W} \times FV \times 0.9 \quad (\text{eq. 3.4})$$

Where:

ΔA = Absorbance read against the reagent blank

$$F = \frac{100 \text{ (}\mu\text{g of D-glucose)}}{\text{Absorbance for 100 } \mu\text{g of glucose}} \text{ (conversion from absorbance to } \mu\text{g)}$$

FV = Final volume (mL)

W = Sample weight (mg)

0.9 = Adjustment from free D-glucose to anhydro D-glucose (as occurs in starch).

j) Oligosaccharides

About 50 mg sample was measured and extracted by 1 mL of 1200 $\mu\text{g/mL}$ of D-arabinose water solution at 60 °C for 1 h. After that, the mixture was centrifuged at 14,000 rpm for 10 min. The supernatant was collected. The extraction procedure was repeated by adding 0.5 mL of distilled water and the supernatants were combined. A 0.75 mL of supernatant was mixed with 0.75 mL of 100% acetonitrile by vortexing. The solution was incubated at room temperature for 10 min and centrifuged at 14,000 rpm for 10 min. The supernatant was collected, filtered through 0.2 μm membrane and analyzed by Acquity UltraPerformance LC (Waters Corporation, MA, USA). The oligosaccharide content (raffinose, stachyose and verbascose) was calculated by the external standard curves prepared with the corresponding oligosaccharide (50 to 400 $\mu\text{g/mL}$). D-arabinose was used as the internal standard for the calculation of recovery factor. The oligosaccharides content was calculated by the following equations (eq. 3.5 and 3.6).

$$\text{Recovery factor} = \frac{\text{Concentration of D-arabinose in the extract}}{400} \quad (\text{eq. 3.5})$$

$$\text{Oligosaccharide\%} = \frac{\text{Concentration of oligosaccharide in the extract} \times 3}{\text{Recovery factor} \times \text{Sample weight}} \times 100\% \quad (\text{eq. 3.6})$$

k) Lipoxygenase activity

The lipoxygenase activity of fibre products was analyzed by a modified method (Chang & McCurdy, 1985). Two g sample was extracted with 0.05 M phosphate buffer (pH 6.9, 1:10 m/v) for 2 h at 4 °C. The slurry was centrifuged at 10,000 g for 30 min at 4 °C and filtered to obtain the crude extract. Ten μL of crude extract was pipetted into a quartz cuvette containing 3 mL of linoleic acid substrate (0.0946 mM) and monitored at 234 nm using a UV spectrophotometer (Shimadzu Corporation, Kyoto, Japan, Model UV-1800). The absorbance was recorded every 5

sec for 5 min and absorbance values were plotted against time. One unit of lipoxygenase activity was equivalent to the increase in absorbance of 0.001 units per minute. The lipoxygenase activity was presented as units per mg extractable protein measured by the Bradford assay (Bradford, 1976).

3.3.3 Analysis of functional properties

a) *Water holding capacity*

The water holding capacity (WHC) was estimated using the modified AACC Method 56 - 20.01 (AACC, 1999). About 1 g sample was accurately weighed into the tube and mixed thoroughly with 20 mL of distilled water by vortex mixer for 1 min. The suspension was let stand 10 min at room temperature and mixed for 15 sec at 5 min and 10 min. After centrifugation, the supernatant was carefully decanted and the tube was inverted to drain. The weight of both tube and sediment was recorded and the water holding capacity was calculated by the following equation.

$$\text{WHC, g/g} = \frac{(\text{tube weight} + \text{sediment weight}) - (\text{tube weight} + \text{sample weight})}{\text{sample weight}} \quad (\text{eq. 3.7})$$

b) *Oil absorption capacity*

The oil absorption capacity (OAC) was evaluated by the method of Lin et al. (1974). About 1 g sample was mixed thoroughly with 5 mL of corn oil for 1 min in the centrifuge tube. After staying for 30 min at room temperature, the tube was centrifuged for 25 min. Excess oil was carefully decanted and drained and the tube was weighed again. The oil absorption capacity was calculated according to the following equation.

$$\text{OAC, g/g} = \frac{(\text{tube weight} + \text{sediment weight}) - (\text{tube weight} + \text{sample weight})}{\text{sample weight}} \quad (\text{eq. 3.8})$$

c) *Hot absorption*

The hot absorption was analyzed using a reported method (Comer, 1979). About 1 g sample was mixed with 40 mL 5% NaCl (w/w) for 1 min and kept in a 75 °C water bath for 45 min. The tube was stirred thoroughly for 15 sec at 15, 30 and 45 min and then cooled in the cold water bath. After centrifugation at 4,750 rpm for 15 min, the supernatant was decanted carefully and the tube with wet sample was weighed. Hot absorption was calculated according to eq. 3.9.

$$\text{Hot absorption, g/g} = \frac{(\text{tube weight} + \text{sediment weight}) - (\text{tube weight} + \text{sample weight})}{\text{sample weight}} \quad (\text{eq. 3.9})$$

d) Pasting properties

The pasting properties of fibre samples were analyzed by AACC method 76-21.01 (AACC, 1999) using a Rapid Visco Analyser (Newport Scientific Pty Limited, Australia). The standard 1 test profile was used and the details are shown in Table 3-1 and Figure 3-2. All the fibre samples were done in triplicate.

e) Pasting properties by bologna cooking method

The change of viscosity of fibre samples at the temperatures of bologna cooking conditions was recorded by the Rapid Visco Analyser with modified profile shown in Table 3-1 and Figure 3-2. The only difference with standard 1 profile was changing the holding temperature from 95 °C to 75 °C (which is the final temperature for bologna cooking). All the samples were done in triplicate.

Table 3-1 Profile of standard 1 and bologna cooking method

Stage	Standard 1		Bologna cooking method	
	Temperature/Speed	Time	Temperature/Speed	Time
1	50 °C	0 min, 0 sec	50 °C	0 min, 0 sec
2	960 rpm	0 min, 0 sec	960 rpm	0 min, 0 sec
3	160 rpm	0 min, 10 sec	160 rpm	0 min, 10 sec
4	50 °C	1 min, 0 sec	50 °C	1 min, 0 sec
5	95 °C	4 min, 42 sec	75 °C	4 min, 42 sec
6	95 °C	7 min, 12 sec	75 °C	7 min, 12 sec
7	50 °C	11 min, 0 sec	50 °C	11 min, 0 sec
End of test		13 min, 0 sec		13 min, 0 sec

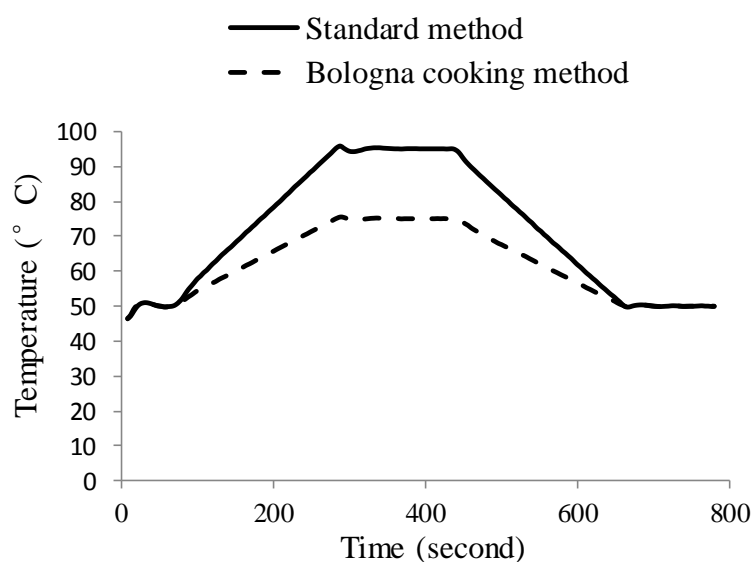


Figure 3-2 Profile of standard method and bologna cooking method

3.3.4 Statistical analysis

The mean and standard deviation were calculated with triplicate measurements and three replicates for all samples. Data were analyzed by one-way analysis of variance (ANOVA) using the Statistical Package of R software. The significance was declared at $p < 0.05$. Pearson correlation coefficients among all the measured parameters were determined using Statistical Product and Service Solutions (SPSS).

3.4 Results and discussion

3.4.1 Sample preparation

The HT and non-HT fibre fractions of yellow pea and red lentil after dehulling and sieving are shown in Figure 3-3. After milling of these fibre fractions they became finer flour and their particle size distribution is presented in Figure 3-4.



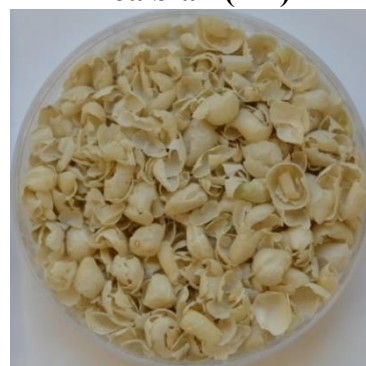
Pea bran



Pea bran (HT)



Pea fibre concentrate



Pea fibre concentrate (HT)



Lentil bran



Lentil bran (HT)



Lentil fibre concentrate



Lentil fibre concentrate (HT)

Figure 3-3 Images of heat treated (HT) and non-HT fibre fractions of yellow pea and red lentil as received.

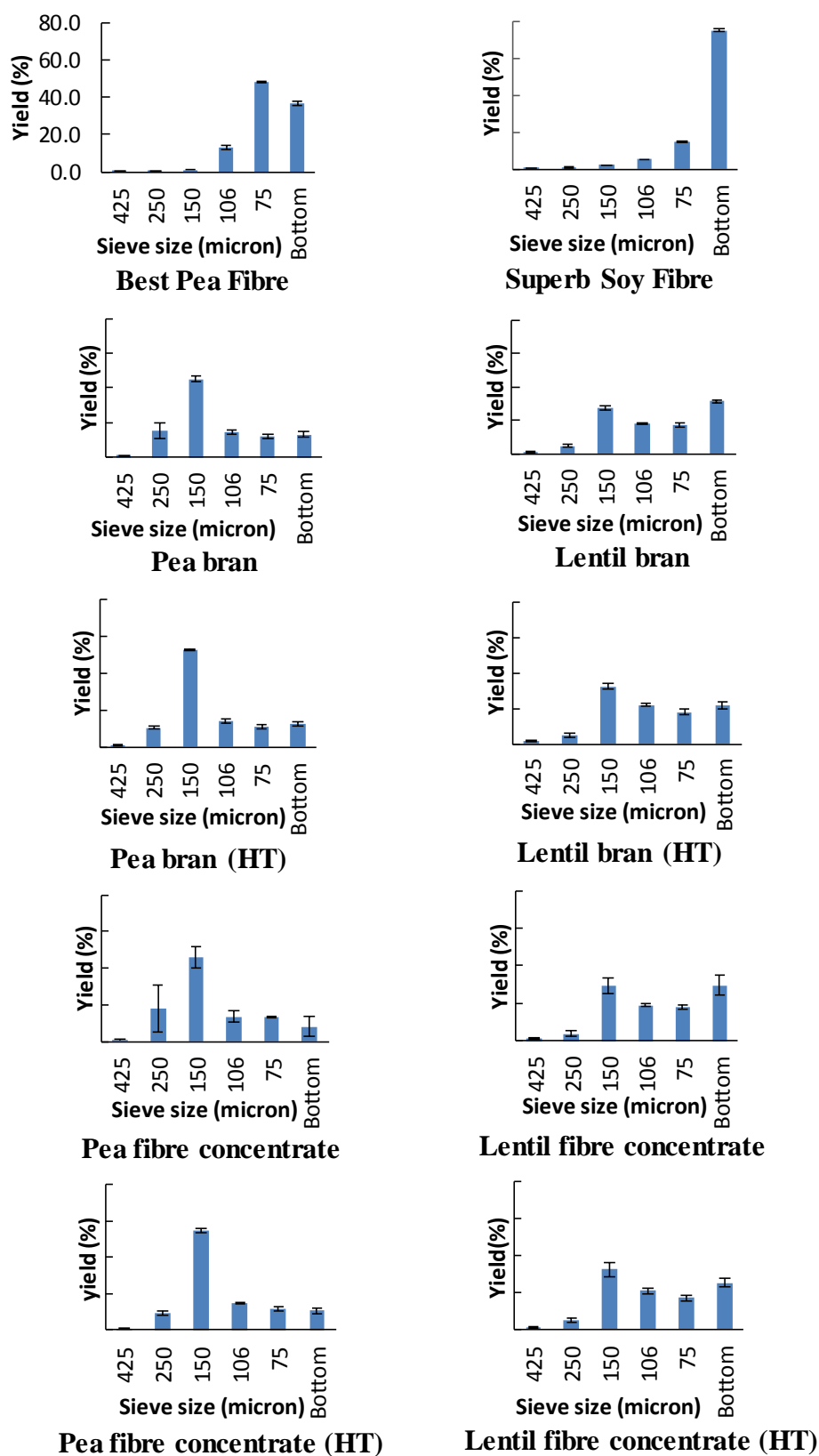


Figure 3-4 Particle size distribution of heat treated (HT) and non-HT fibre fractions of yellow pea and red lentil after milling (n = 3).

In Figure 3-3, the fibre fractions of yellow pea showed light yellow colour. Sieving (mesh size was 1000 micron and 2500 micron for red lentil and yellow pea, respectively) could separate the pea fibre fractions into two parts with different size. The pea fibre concentrate still kept the round shape of the whole seed, while pea bran was smaller broken particles. No cotyledon particles or pieces could be visually found in both pea bran and pea fibre concentrate. Lentil fibre fractions were dark brown in colour. Large pieces of cotyledons could be seen in lentil fibre concentrate. Smaller and finer particles similar to flour of cotyledon were also found in lentil bran. This indicated that dehulling alone could not completely separate the seed coats from cotyledons of red lentil. The efficiency of dehulling is affected by seed characteristics such as size and shape, the content and thickness of seed coat, and the adherence of the seed coat to the cotyledon. The seed coat of lentil is thin and accounts for 5-10% of the grain (Pratape et al., 2003). The incomplete separation of the seed coat and cotyledon of red lentil possibly resulted from its relatively small seed size, thin seed coat and flat lens shape.

In Figure 3-4, all fibre fractions were less than 425 micron after milling. For yellow pea and red lentil, particle size distribution from the same variety was similar. Finer particles were found in fibre fractions of red lentil than in yellow pea. The possible explanation might be that cotyledons were more easily broken into fine particles compared with the seed coats during milling. The two commercial products Best Pea Fibre and Superb Soy Fibre showed much finer particles than pea and lentil fibre fractions with 84.7% and 90.4% of particles less than 106 micron, respectively.

3.4.2 Physicochemical properties

a) Colour measurement

Two commercial products Best Pea Fibre and Superb Soy Fibre showed the highest L* (lightness) values followed by pea fibre fractions and then lentil fibre fractions, indicating their lighter colour (Table 3-2). Pea fibre fractions were lighter than lentil fibre fractions which was demonstrated by their higher L* values. Wang and Toews (2011) also reported that lentil fibre fractions had the lowest lightness values among all the other fibre fractions from pulse cotyledons. No significant difference in L* value was found between the bran and fibre concentrate of the same variety. For a* (redness) values, the highest value was observed in lentil fibre fractions, which was followed by Superb Soy Fibre and then Best Pea Fibre. Pea fibre fractions showed the lowest a* values. Again, there was no significant difference found in a*

value in the same variety. The higher a^* values for lentil fibre fractions resulted from the brown and orange colour of their seed coats and cotyledons, respectively. Others have also observed that red lentil is redder in colour than yellow pea (Ma et al., 2011; Wang & Toews, 2011). Also, the commercial product Superb Soy Fibre had an orange colour compared with the light yellow colour of pea fibre fractions and Best Pea Fibre. For b^* (yellowness) values, the Superb Soy Fibre had the highest value followed by lentil fibre fractions and Best Pea Fibre, and then pea fibre fractions. The higher yellowness of lentil fibre fractions than pea fibre fractions was confirmed by Wang and Toews (2011) even though their fibre products were mainly from cotyledons rather than seed coats. No significant difference was found in lentil fibre fractions while pea bran showed higher b^* values than pea fibre concentrate. Overall, Best Pea Fibre had similar colour characteristics with pea bran except for its slightly higher a^* value. The different colour characteristics of fibre products were mainly attributed to the different pigments of legume varieties. Generally, lab-scale hydrothermal treatment did not induce any changes in the colour except the increased L^* value and decreased a^* value found for HT lentil fibre concentrate. From the results of proximate analysis it can be postulated that the colour change was due to the loss of seed coat particles rather than the heat effect.

Table 3-2 Objective colour of HT and non-HT fibre fractions of yellow pea and red lentil (n=3)

Treatment	L^*	a^*	b^*
Pea bran	77.75 ± 1.36^{ab}	4.29 ± 0.17^e	15.86 ± 0.54^{cd}
Pea bran (HT)	78.67 ± 0.10^{ab}	4.20 ± 0.07^e	15.60 ± 0.25^{de}
Pea fibre concentrate	76.98 ± 0.53^b	4.04 ± 0.12^e	14.50 ± 0.30^f
Pea fibre concentrate (HT)	77.14 ± 0.86^b	4.12 ± 0.11^e	14.86 ± 0.33^{ef}
Lentil bran	68.92 ± 0.71^{cd}	7.30 ± 0.05^{ab}	16.76 ± 0.01^b
Lentil bran (HT)	68.24 ± 1.76^{cd}	7.15 ± 0.07^{ab}	16.62 ± 0.13^{bc}
Lentil fibre concentrate	66.74 ± 0.51^d	7.46 ± 0.05^a	16.59 ± 0.13^{bc}
Lentil fibre concentrate (HT)	70.30 ± 1.13^c	7.04 ± 0.30^b	16.53 ± 0.59^{bc}
Best Pea Fibre	79.88 ± 0.33^a	5.10 ± 0.01^d	16.45 ± 0.03^{bcd}
Superb Soy Fibre	80.42 ± 0.65^a	6.21 ± 0.03^c	18.05 ± 0.09^a

Values are presented as mean \pm standard deviation

^{a-f}. Means with different superscripts are significantly different ($p < 0.05$)

b) Moisture

The values of moisture content of fibre products are presented in Table 3-3. The lentil fibre fractions showed higher moisture content than pea fibre fractions, and no significant difference was found between the bran and fibre concentrate for both varieties. Hydrothermal treatment effectively reduced the moisture content of the fibre fractions to the same level as the two commercial products and therefore prevented microbial growth during the storage.

Table 3-3 Proximate analysis of heat treated (HT) and non-HT fibre fractions of yellow pea and red lentil (n=3)

Treatment	Moisture (%)	Protein (%)	Ash (%)	Fat (%)	Starch (%)
Pea bran	5.92 ± 0.38 ^{bc}	8.16 ± 0.96 ^d	2.87 ± 0.09 ^{cd}	0.65 ± 0.11 ^d	4.79 ± 1.03 ^d
Pea bran (HT)	2.97 ± 0.39 ^{def}	8.00 ± 0.33 ^{de}	2.83 ± 0.04 ^{cd}	0.63 ± 0.03 ^{de}	4.36 ± 0.31 ^d
Pea fibre conc.	5.15 ± 0.42 ^c	4.44 ± 0.21 ^f	2.72 ± 0.02 ^d	0.39 ± 0.09 ^{ef}	0.85 ± 0.03 ^e
Pea fibre conc. (HT)	2.36 ± 0.18 ^f	4.67 ± 0.00 ^f	2.74 ± 0.07 ^d	0.35 ± 0.07 ^f	1.14 ± 0.12 ^e
Lentil bran	6.92 ± 0.25 ^a	23.18 ± 0.38 ^b	3.52 ± 0.01 ^b	1.43 ± 0.07 ^a	14.75 ± 0.51 ^c
Lentil bran (HT)	3.48 ± 0.20 ^{de}	22.58 ± 0.83 ^b	3.97 ± 0.43 ^a	1.15 ± 0.19 ^{bc}	14.70 ± 1.75 ^c
Lentil fibre conc.	6.45 ± 0.29 ^{ab}	21.16 ± 0.20 ^c	2.99 ± 0.03 ^{cd}	1.16 ± 0.06 ^{bc}	17.44 ± 0.59 ^b
Lentil fibre conc. (HT)	3.75 ± 0.58 ^d	23.43 ± 0.08 ^b	3.06 ± 0.05 ^{cd}	1.37 ± 0.02 ^{ab}	23.29 ± 0.50 ^a
Best Pea Fibre	3.28 ± 0.02 ^{def}	6.73 ± 0.01 ^e	2.72 ± 0.04 ^d	0.56 ± 0.00 ^{def}	4.00 ± 0.03 ^d
Superb Soy Fibre	2.72 ± 0.06 ^{ef}	36.98 ± 0.27 ^a	3.19 ± 0.02 ^{bc}	1.07 ± 0.06 ^c	0.84 ± 0.02 ^e

All the data except moisture are on dry basis

Values are presented as mean ± standard deviation

^{a-f}: Means with different superscripts are significantly different ($p < 0.05$)

fibre conc. = fibre concentrate

c) Protein

In Table 3-3, it could be seen that lentil fibre fractions had much higher protein content than pea fibre fractions, resulting from cotyledon contamination during dehulling. Pea bran showed significantly higher protein content than pea fibre concentrate. The increased values for protein could be attributed to the cotyledon contamination or from the protein attached to the inner seed coat. For red lentil, the difference in the protein content between bran and fibre concentrate was significant ($p < 0.05$) but not very large (~ 2%). Lab-scale hydrothermal treatment did not affect protein content of fibre products except for the increased value for HT lentil fibre concentrate. This could be the evidence showing the loss of seed coats during the treatment. Superb Soy Fibre

had the highest protein content among all the fibre products. Best Pea Fibre showed a moderate value between pea bran and pea fibre concentrate.

The protein contents of the whole seed of yellow pea and red lentil were reported as 23.7% and 25.7%, respectively (Wang & Daun, 2004). Since the fibre products of the present study were obtained from commercial scale dehulling, more seed coat particles and less cotyledons were expected in comparison to the whole seed. Protein content can be considered as an indicator of more cotyledon particles in the product. The pea fibre fractions showed a huge reduction in the protein content while lentil fibre fractions showed higher and similar values with the whole seed. It meant that dehulling could remove most of cotyledons from yellow pea and concentrate seed coats.

d) Ash

The ash content of all the samples were in the range of 2.72% to 3.97%. The highest value was observed in lentil bran and Superb Soy Fibre. The other fibre products showed no significant difference in the ash content. Hydrothermal treatment did not affect ash content of all fibre products but it increased the ash content of lentil bran. Best Pea Fibre showed similar ash content with pea fibre fractions. The reported ash content of whole seed of pea and lentil was 2.3 - 3.5% and red lentil was slightly higher than yellow pea (Wang & Daun, 2004). The seed coat contained more ash than the cotyledon. Therefore, the fibre fractions of yellow pea and red lentil should contain more ash content than the reported data for the whole seed. Our result showed that lab-scale hydrothermal treatment increased the ash content of lentil bran. However, Hefnawy (2011) and Wang et al. (2009) have reported opposite results. They used different cooking methods to treat lentils and found that the ash content was significantly reduced because of its leaching into cooking water. The increased ash content in these fibre samples might be explained by different sample lots.

e) Fat

Lentil fibre fractions showed significantly higher fat content than pea fibre fractions (Table 3-3) because of cotyledon contamination. For yellow pea, bran had higher fat content than fibre concentrate, indicating less cotyledon contamination. For red lentil, bran showed significantly higher fat content than fibre concentrate. Hydrothermal treatment did not significantly affect fat content of most fibre products, but it decreased the fat content of lentil bran. Generally, pulses

are very low in fat and the reported data for the whole seed of pea and lentil was 1.0 - 1.7% (Wang & Daun, 2004). The cotyledon was the main storage place for oil. Pea fibre fractions showed much lower value than the reported data because they included more seed coats. Lentil fibre fractions had similar values with the reported data because of the cotyledon contamination. Best Pea Fibre showed similar fat content with pea fibre fractions and Superb Soy Fibre contained 1.07% fat content.

f) Starch

Overall, pea fibre fractions contained less starch than lentil fibre fractions. The starch content for pea bran and pea fibre concentrate were 4.79% and 0.85%, respectively, while for lentil bran and lentil fibre concentrate values were 14.75% and 17.44%, respectively. According to the published data, starch content of pea and lentil whole seed was around 45.0% (Wang & Daun, 2004). Therefore, the results suggested that dehulling could effectively separate the cotyledon and seed coat for yellow pea. However, the dehulling and separation operations used for preparing samples of the present study had concentrated seed coats of red lentil with considerable amounts of cotyledons. The possible explanation for the incomplete separation could be the relatively small seed size and thin seed coat of red lentil. Additionally, the protein content of these lentil fibre fractions was close to the value of lentil seed (25.7%), while their starch content was much less than that of whole seed (45.0%). This could be explained by the removal of outer layers of lentil cotyledons along with seed coat during dehulling. It was reported that more protein and less starch are present in outer layers of lentil cotyledons than in inner layers (Wang, 2008). Therefore, more protein will be removed along with seed coats during dehulling than starch. For yellow pea, the pea fibre concentrate showed even less starch content than pea bran indicating that sieving could further purify the seed coat. Again, this also did not work for red lentil because lentil fibre concentrate had slightly higher starch content than lentil bran. Hydrothermal treatment did not bring any impacts on most of the fibre products but it was clear that it could significantly increase the starch content of lentil fibre concentrate. Instead of the heat effect, we believed that this huge increase came from the loss of seed coats during the treatment, which was supported by the increased values in protein and fat content and also by the reduced values in total phenolics and dietary fibre content (data presented later). Best Pea Fibre contained 4 % starch, which was similar to pea bran. Superb Soy Fibre had the least starch

content (0.84%) among all fibre products, which was close to the values (less than 1%) reported for mature soybean seed and soybean flour (Redondo-Cuenca et al., 2007; Wilson et al., 1978).

g) Phenolic compounds

The phenolic compounds of fibre products were extracted by 70% acetone and redissolved in 80% ethanol for measurement. The results are shown in Table 3-4.

Table 3-4 Phenolic compounds of heat treated (HT) and non-HT fibre fractions of yellow pea and red lentil (n=3)

Treatment	Total phenolics (mg catechin equivalents/g)	Tartaric esters (mg caffeic acid equivalents/g)	Flavonols (mg quercetin equivalents/g)
Pea bran	9.72 ± 0.14 ^c	1.08 ± 0.01 ^{bc}	0.34 ± 0.04 ^c
Pea bran (HT)	9.73 ± 0.10 ^c	1.07 ± 0.01 ^{bc}	0.32 ± 0.03 ^c
Pea fibre concentrate	8.29 ± 0.11 ^c	0.86 ± 0.01 ^d	0.18 ± 0.01 ^c
Pea fibre concentrate (HT)	8.36 ± 0.20 ^c	0.87 ± 0.02 ^d	0.17 ± 0.02 ^c
Lentil bran	55.75 ± 2.03 ^a	1.54 ± 0.11 ^a	1.84 ± 0.15 ^a
Lentil bran (HT)	58.40 ± 5.94 ^a	1.50 ± 0.04 ^a	1.66 ± 0.09 ^a
Lentil fibre concentrate	56.65 ± 1.74 ^a	1.22 ± 0.08 ^b	1.27 ± 0.08 ^b
Lentil fibre concentrate (HT)	44.05 ± 1.78 ^b	1.16 ± 0.10 ^b	1.32 ± 0.11 ^b
Best Pea Fibre	9.79 ± 0.48 ^c	0.98 ± 0.02 ^{cd}	0.27 ± 0.01 ^c
Superb Soy Fibre	7.38 ± 0.26 ^c	0.12 ± 0.01 ^e	n.d.

All the data are on dry basis

Values are presented as mean ± standard deviation

^{a-d}: Means with different superscripts were significantly different ($p < 0.05$)

n.d.: not detectable

The total phenolics, tartaric esters and flavonols of fibre fractions of red lentil fibre fractions were significantly higher than those of yellow pea (Table 3-4). Usually, more coloured seeds showed more phenolics than pale seeds (Deshpande et al., 1982). This was supported by our results. For yellow pea, there was no significant difference between bran and fibre concentrate in their total phenolics and flavonols but pea bran showed higher tartaric esters than pea fibre concentrate. On the other hand, lentil bran and lentil fibre concentrate showed similar values in total phenolics. Higher values in the content of tartaric esters and flavonols were found in lentil bran than in lentil fibre concentrate. In general, lab-scale hydrothermal treatment had no

significant impact on the phenolic compounds for all fibre products except for lentil fibre concentrate with lower total phenolic content after treatment because of the loss of seed coat. Best Pea Fibre had similar phenolic content with pea fibre fractions and Superb Soy Fibre showed the lowest values among all the fibre products. In this study, we also measured the anthocyanin content and its concentration was too low to be detected.

Xu and Chang (2007) investigated the phenolic compounds of different pulses. According to their results, yellow pea and lentil had 1.67 mg/g and 6.56 mg/g total phenolics, respectively. However, they used a different extraction solvent and a quantitation method. Therefore, these values are not comparable with our results. Oomah et al. (2011) extracted the phenolic compounds of yellow pea and red lentil with 70% (v/v) acetone and the results showed that their total phenolics of hulls were 6.89 and 87.16 mg (+) catechin/g sample (dry matter basis), respectively, which was close to the results of the present study. In addition, their result proved that seed coat contained more phenolic compounds than whole seed and residues.

h) Total, Soluble, and Insoluble dietary fibre

The total, soluble, and insoluble dietary fibre contents (TDF, SDF and IDF) of all fibre fractions are shown in Table 3-5.

Table 3-5 TDF, IDF and SDF of heat treated (HT) and non-HT fibre fractions of yellow pea and red lentil (n=3)

Treatment	TDF (%)	IDF (%)	SDF (%)
Pea bran	79.27 ± 2.24 ^b	74.22 ± 2.15 ^b	5.05 ± 0.24 ^{bc}
Pea bran (HT)	79.39 ± 1.67 ^b	74.67 ± 1.47 ^b	4.73 ± 0.22 ^{bcd}
Pea fibre concentrate	88.79 ± 0.89 ^a	83.49 ± 0.60 ^a	5.30 ± 0.30 ^{bc}
Pea fibre concentrate (HT)	88.17 ± 0.47 ^a	82.80 ± 0.64 ^a	5.37 ± 0.64 ^{bc}
Lentil bran	46.60 ± 0.30 ^d	42.10 ± 1.24 ^d	4.49 ± 1.03 ^{bcd}
Lentil bran (HT)	49.16 ± 5.59 ^d	44.80 ± 5.20 ^{cd}	4.35 ± 0.43 ^{cd}
Lentil fibre concentrate	50.04 ± 3.14 ^d	45.54 ± 2.27 ^{cd}	4.50 ± 0.88 ^{bcd}
Lentil fibre concentrate (HT)	37.99 ± 0.15 ^e	34.46 ± 0.20 ^e	3.53 ± 0.15 ^d
Best Pea Fibre	80.79 ± 0.47 ^b	73.28 ± 0.27 ^b	7.52 ± 0.20 ^a
Superb Soy Fibre	56.64 ± 0.34 ^c	50.63 ± 0.05 ^c	6.01 ± 0.31 ^{ab}

All the data are on dry basis

Values are presented as mean ± standard deviation

^{a-e}: Means with different superscripts are significantly different ($p < 0.05$)

Overall, pea fibre fractions contained 79.27% - 88.79% total dietary fibre (TDF), which were higher than lentil fibre fractions (46.60% - 50.04%). The lower values of lentil fibre fractions were due to the cotyledon contamination. For the dietary fibre composition, both varieties were mainly composed of insoluble dietary fibre (IDF) (90.36% - 94.05%) rather than soluble dietary fibre (SDF) (5.95% - 9.64%). The highest fibre content was obtained by pea fibre concentrate. Pea fibre concentrate had a significantly higher TDF than pea bran, confirming the effectiveness of sieving to obtain a more concentrated seed coat portion with higher dietary fibre content. Additionally, the higher total dietary fibre content resulted from the increase in IDF rather than SDF. In contrast, lentil bran and lentil fibre concentrate had no significant difference in the TDF content (46.60% and 50.04%, respectively) and they also showed similar content in IDF and SDF. Lab-scale hydrothermal treatment had no significant influence on the dietary fibre content of most fibre products but it dramatically reduced the TDF of lentil fibre concentrate from 50.04% to 37.99%. This is clear evidence for the loss of seed coats during the treatment as seed coat has high dietary fibre content (Wang, 2008). Best Pea Fibre contained 80.79% TDF with 73.28% IDF and 7.52% SDF. These values were similar to those of pea fibre fractions except for its higher content of SDF. Superb Soy Fibre had 56.64% TDF (50.63% IDF and 6.01% SDF), which was slightly higher than those of lentil fibre fractions.

Wang and Toews (2011) have investigated the fibre fractions of cotyledons from different pulse varieties. Their results showed that pea fibre fractions and lentil fibre fractions contained 70.76 - 80.46% and 66.32 - 72.75% TDF, respectively. IDF accounted for 93.20 - 95.08% TDF. The lentil fibre fractions used in Wang and Toews' study had higher TDF than ours which were mainly attributed to their different fibre extraction method. They also used Best Pea Fibre as the reference but had lower TDF (75.80%) when compared with our findings. This may have resulted from use of different fibre sample lots and analytical methods.

i) Oligosaccharides

The levels of oligosaccharides of yellow pea and lentil fibre products are shown in Table 3-6.

Table 3-6 Oligosaccharides of heat treated (HT) and non-HT fibre fractions of yellow pea and red lentil (n=3).

Treatment	Raffinose (%)	Stachyose (%)	Verbascose (%)
Pea bran	0.14 ± 0.04 ^a	0.87 ± 0.26 ^a	0.52 ± 0.17 ^a
Pea bran (HT)	0.15 ± 0.04 ^a	0.82 ± 0.14 ^{ab}	0.46 ± 0.09 ^a
Pea fibre concentrate	0.06 ± 0.01 ^b	0.31 ± 0.04 ^{cd}	0.22 ± 0.03 ^b
Pea fibre concentrate (HT)	0.06 ± 0.01 ^b	0.31 ± 0.03 ^{cd}	0.21 ± 0.02 ^b
Lentil bran	0.04 ± 0.01 ^b	0.71 ± 0.20 ^{ab}	0.46 ± 0.10 ^a
Lentil bran (HT)	0.01 ± 0.01 ^b	0.48 ± 0.10 ^{bcd}	0.41 ± 0.02 ^{ab}
Lentil fibre concentrate	0.05 ± 0.02 ^b	0.61 ± 0.09 ^{abc}	0.39 ± 0.05 ^{ab}
Lentil fibre concentrate (HT)	0.07 ± 0.01 ^b	0.81 ± 0.11 ^{ab}	0.46 ± 0.04 ^a
Best Pea Fibre	0.17 ± 0.00 ^a	0.46 ± 0.02 ^{bcd}	0.34 ± 0.03 ^{ab}
Superb Soy Fibre	n.d.	0.15 ± 0.02 ^d	n.d.

All the data are on dry basis

Values are presented as mean ± standard deviation

^{a-d}: Means with different superscripts are significantly different ($p < 0.05$)

n.d.: not detectable

All fibre products were very low in oligosaccharides with values less than 2% in total. For the raffinose, Best Pea Fibre and pea bran had the highest values. All the other fibre products had significantly lower raffinose content than pea bran regardless of different pulse varieties. Stachyose was the dominant oligosaccharide found in all fibre products. Pea bran and lentil fibre fractions had no significant difference in stachyose content, which was higher than pea fibre concentrate and Best Pea Fibre. For verbascose, all the fibre products showed similar values except for pea fibre concentrate with a significantly lower value. The Super Soy Fibre only contained traces of stachyose. Lab-scale hydrothermal treatment had no effects on the oligosaccharide content of all fibre products.

Wang and Daun (2004) reported that yellow pea had 0.7% raffinose, 2.7% stachylose and 1.0% verbascose and red lentil included 0.42% raffinose, 1.94% stachyose and 0.52% verbascose. Cooked yellow pea and red lentil contained 8.87 and 1.61 mg/g raffinose, 20.62 and 17.61 mg/g stachyose and 15.56 and 11.04 mg/g verbascose, respectively (Brummer et al., 2015). These values are higher than those obtained in our experiment. It was observed that dehulling would increase the oligosaccharides content of field pea (Wang et al., 2008), indicating that more oligosaccharides are present in cotyledons than seed coats. This could be the reason for our

lower values. Also, the higher oligosaccharide content found in pea bran than pea fibre concentrate could be explained by the presence of more cotyledons.

j) Lipoxygenase activity

The lipoxygenase (LOX) activity of fibre products are presented in Table 3-7.

Table 3-7 Lipoxygenase activity of heat treated (HT) and non-HT fibre fractions of yellow pea and red lentil (n=3).

Treatment	Lipoxygenase activity (units)	Lipoxygenase activity ($\times 10^3$ units/mg extractable protein)
Pea bran	156.52 \pm 35.57 ^a	13.77 \pm 1.79 ^a
Pea bran (HT)	126.05 \pm 19.15 ^a	10.74 \pm 2.07 ^a
Pea fibre concentrate	42.58 \pm 2.83 ^b	11.00 \pm 2.47 ^a
Pea fibre concentrate (HT)	39.41 \pm 6.89 ^b	9.71 \pm 1.27 ^a
Lentil bran	41.72 \pm 11.52 ^b	4.56 \pm 1.63 ^b
Lentil bran (HT)	33.44 \pm 32.50 ^b	4.40 \pm 1.75 ^b
Lentil fibre concentrate	14.73 \pm 5.33 ^b	3.27 \pm 0.57 ^b
Lentil fibre concentrate (HT)	119.37 \pm 20.76 ^a	9.32 \pm 1.12 ^a
Best Pea Fibre	9.42 \pm 0.91 ^b	2.46 \pm 0.31 ^b
Superb Soy Fibre	n.d.	n.d.

All the data are on dry basis

Values are presented as mean \pm standard deviation

^{a-b}: Means with different superscripts are significantly different ($p < 0.05$)

n.d.: not detectable

The lipoxygenase activity of fibre products was presented as units/mg extractable protein. Overall, pea fibre fractions had higher LOX activity than lentil fibre fractions and no significant difference was found between the same varieties. Lab-scale hydrothermal treatment did not bring any effects on the LOX activity of most of the samples, meaning that this lab-scale treatment was not effective. The only exception was the increased LOX activity found in HT lentil fibre concentrate. Again, this increase was more likely due to its increased cotyledon content rather than the heat effect. LOX activity of the Best Pea Fibre was very low and not detected in the Superb Soy Fibre. To be comparable to Best Pea Fibre, more severe heat treatment should be applied to lower LOX activity of pea fibre fractions.

The presence of LOX in food products was deleterious because it could catalyze the hydroperoxidation of polyunsaturated fatty acids and produce off-flavors (Szymanowska et al., 2009). Chang and McCurdy (1985) reported that the LOX activity of pea and lentil were $5.76 - 6.76 \times 10^6$ and 24.12×10^6 units/extractable protein, respectively. These values were much higher than the results of present study possibly because our samples had less cotyledons. Their results also showed that lentil had higher LOX activity than pea which was opposite to the results of our samples. The possible explanation was that the extractable protein content of pea fibre fractions were higher than lentil fibre fractions (data not shown) even though their total protein content was much lower. Another possible reason was that lentil fibre fractions had much more phenolic compounds (results shown in Table 3-4) which were reported to inhibit LOX activity by many studies (Duque et al., 2011; Goupy et al., 1999). Kubicka et al. (2003) found that phenolic extracts from lentil seed coat could effectively inhibit the soybean lipoxygenase activity.

3.4.3 Functional properties

a) Water holding capacity, oil absorption capacity and hot absorption

Water holding capacity (WHC) and oil absorption capacity (OAC) were two important functional properties of fibre products. These properties were associated with the yield of cooked food products, food texture and flavor, and also food safety (Du et al., 2014a). WHC and OAC of fibre products could be affected by various factors. The first and most important factor was the chemical composition such as the protein, starch and dietary fibre content and their structural characteristics such as the ratio of amino acids with polar and non-polar side chains on the protein molecule surface, SDF and IDF ratio of dietary fibre, and gelatinization extent of starch. Another factor was their physical properties including particle size and porosity. Additionally, the environment factors, for example, pH value, temperature and ion strength and processing history could also induce some changes in these functionalities (Cui et al., 2013; Du et al., 2014a; Tosh & Yada, 2010). A consistent method for measurement was important because different methods would lead to different results that can not be compared. In this study, WHC was measured by AACC method 56-20.01 and OAC was measured using a modified method (Lin et al., 1974) with fresh corn oil. The results are shown in Table 3-8.

Table 3-8 Water holding capacity, oil absorption capacity and hot absorption of heat treated (HT) and non-HT fibre fractions of yellow pea and red lentil (n=3)

Treatment	Water holding capacity (g/g)	Oil absorption capacity (g/g)	Hot absorption (g/g)
Pea bran	3.74 ± 0.15 ^a	0.93 ± 0.02 ^d	4.07 ± 0.09 ^{bc}
Pea bran (HT)	3.62 ± 0.18 ^a	0.92 ± 0.01 ^d	4.02 ± 0.05 ^{bc}
Pea fibre concentrate	4.04 ± 0.15 ^a	1.04 ± 0.01 ^c	4.40 ± 0.05 ^a
Pea fibre concentrate (HT)	3.97 ± 0.15 ^a	1.01 ± 0.01 ^c	4.16 ± 0.07 ^b
Lentil bran	3.03 ± 0.05 ^b	0.91 ± 0.01 ^{de}	3.64 ± 0.02 ^d
Lentil bran (HT)	2.85 ± 0.33 ^b	0.88 ± 0.02 ^{ef}	3.46 ± 0.05 ^{ef}
Lentil fibre concentrate	2.61 ± 0.33 ^b	0.90 ± 0.02 ^{de}	3.63 ± 0.07 ^{de}
Lentil fibre concentrate (HT)	2.05 ± 0.06 ^c	0.87 ± 0.02 ^f	3.40 ± 0.07 ^f
Best Pea Fibre	3.62 ± 0.03 ^a	1.17 ± 0.01 ^b	3.95 ± 0.05 ^c
Superb Soy Fibre	4.09 ± 0.01 ^a	1.36 ± 0.01 ^a	3.48 ± 0.04 ^{def}

All the data are on dry basis

Values are presented as mean ± standard deviation

^{a-f}: Means with different superscripts are significantly different ($p < 0.05$)

For water holding capacity, the highest values were obtained for pea fibre fractions, Best Pea Fibre and Superb Soy Fibre. The high WHC of Superb Soy Fibre could result from its high protein content (36.98%) (Chau et al., 1998). Consistent result was reported by Sosulski et al. (1979). They investigated eight legume flours and showed that soybean gave the highest values for WHC. Shand (2000) also reported that soy protein had markedly better water absorption capacity than carbohydrate-based flours. According to our results, the pea bran and Best Pea Fibre had no significant difference in their WHC even though Best Pea Fibre had much finer particle size than pea bran, indicating that the total dietary fibre content might have more effects on the WHC rather than the particle size (Kaur et al., 2005). This was different than the result obtained by Ralet et al. (1993). They observed that ground pea fibre showed higher WHC (3 mL/g) than coarse pea fibre (2.4 mL/g) because of the increased surface area and more exposed polar groups and water-binding sites available to the surrounding water (Zhu et al., 2015). Lentil fibre fractions showed the lowest WHC among all the fibre products and no significant difference was found between lentil bran and lentil fibre concentrate. The reported WHC for lentil starch and fibre fraction were 2.23 g/g and 5.0 - 5.7 g/g, respectively (Ahmed, Thomas, et

al., 2016; Wang & Toews, 2011). Therefore, their lower WHC values were possibly due to their increased starch and decreased dietary fibre content. Lab-scale hydrothermal treatment did not affect WHC of all fibre products except for the lower values found in HT lentil fibre concentrate due to its different chemical composition compared to non-HT one.

Considering the oil absorption capacity, Superb Soy Fibre gave the highest value followed by Best Pea Fibre and pea fibre fractions. Protein based flours were superior in oil absorption compared with carbohydrate based flours because of their hydrophobic groups (Ahmed et al., 2016; Sosulski & Youngs, 1979). This was supported by the result obtained by Sosulski and Youngs (1979) that soybean flour showed the highest OAC value among eight legume flours. Best Pea Fibre had higher OAC than pea fibre concentrate with higher TDF and pea bran with similar chemical composition. The possible explanation was that its smaller particle size with increased surface area could benefit oil absorption (Ahmed et al., 2016; Ma et al., 2016b). On the contrary, finer particle sizes with decreased OAC was also reported by Drakos et al. (2017). They suggested that OAC dominantly depended on the physical entrapment by capillary attraction (Kinsella et al., 1976). The inconsistent results could be due to their different range of particle size and different experimental materials. Pea fibre concentrate had better OAC than pea bran probably due to their higher TDF content (Wang et al., 2016). OAC of dietary fibres was associated with their surface characteristics, overall charge density and hydrophobic groups (Ma et al., 2016a). Additionally, the presence of lignin in dietary fibre would improve its OAC (Sosulski & Cadden, 1982). Therefore, the lowest OAC obtained by lentil fibre fractions could be explained by their lowest TDF even though the presence of more protein could improve the OAC to some extent. Lab-scale hydrothermal treatment brought no significant influence on OAC of all fibre products except for reducing that of lentil fibre concentrate. Again, instead of effects brought from heat, different chemical composition was more likely to account for this reduction.

The method used for measuring hot absorption (HA) was similar to the one used for measuring swelling power except that HA employed NaCl solution rather than distilled water, different temperature (75°C) and longer heating time (45 min rather than 30 min) (Julianti et al., 2015). This was not a standard method and was mainly developed to evaluate the behavior of fibre products under meat cooking condition. It could be seen in Table 3-8 that pea fibre concentrate had the highest HA followed by pea bran and Best Pea Fibre. Generally, all the fibre product could absorb more water at higher temperature (75°C) than at room temperature. This

was demonstrated by their higher HA than WHC, especially for lentil fibre fractions with dramatic increase (20.13% and 39.08%, respectively). It was assumed that this increase was related to the swelling capacity of flour particles at higher temperature because of starch gelatinization and water absorption of non-starch polysaccharide and protein (Ahmed et al., 2016). Starch was well known for its high swelling power in heated water because its amorphous region could greatly absorb water during gelatinization (Agboola et al., 2010; Du et al., 2014b). The gelatinization temperature range for pea and lentil is 59.5 – 75.0 °C and 57.8 – 82.0 °C, respectively (Wani et al., 2016). Pea and lentil starch were reported to swell gradually when temperature increased from 55 to 65 °C and then swell much more above 65 °C (Wang et al., 2014). Higher temperature would also lead to increased water binding capacity and swell capacity of dietary fibre (Fleury et al., 1991). Only Super Soy Fibre showed lower HA value than its WHC value. The possible explanation was that soy protein partially denatured at higher temperature and the exposed hydrophobic groups on the surface of protein molecule repelled the water. It was reported that increased ionic strength could reduce the hydration properties of dietary fibre because the screening of charge could impair electrostatic repulsion between polysaccharides (Fleury & Lahaye, 1991). However, it could stabilize the soy protein against heat treatment and retard the gelation process (Nishinari et al., 2014). All the effects brought by higher temperature and increased ionic strength led to the different HA values of fibre products.

b) Pasting properties

The pasting curve of fibre products (Rep1) obtained by standard method is shown in Figure 3-5 and related parameters are summarized in Table 3-9.

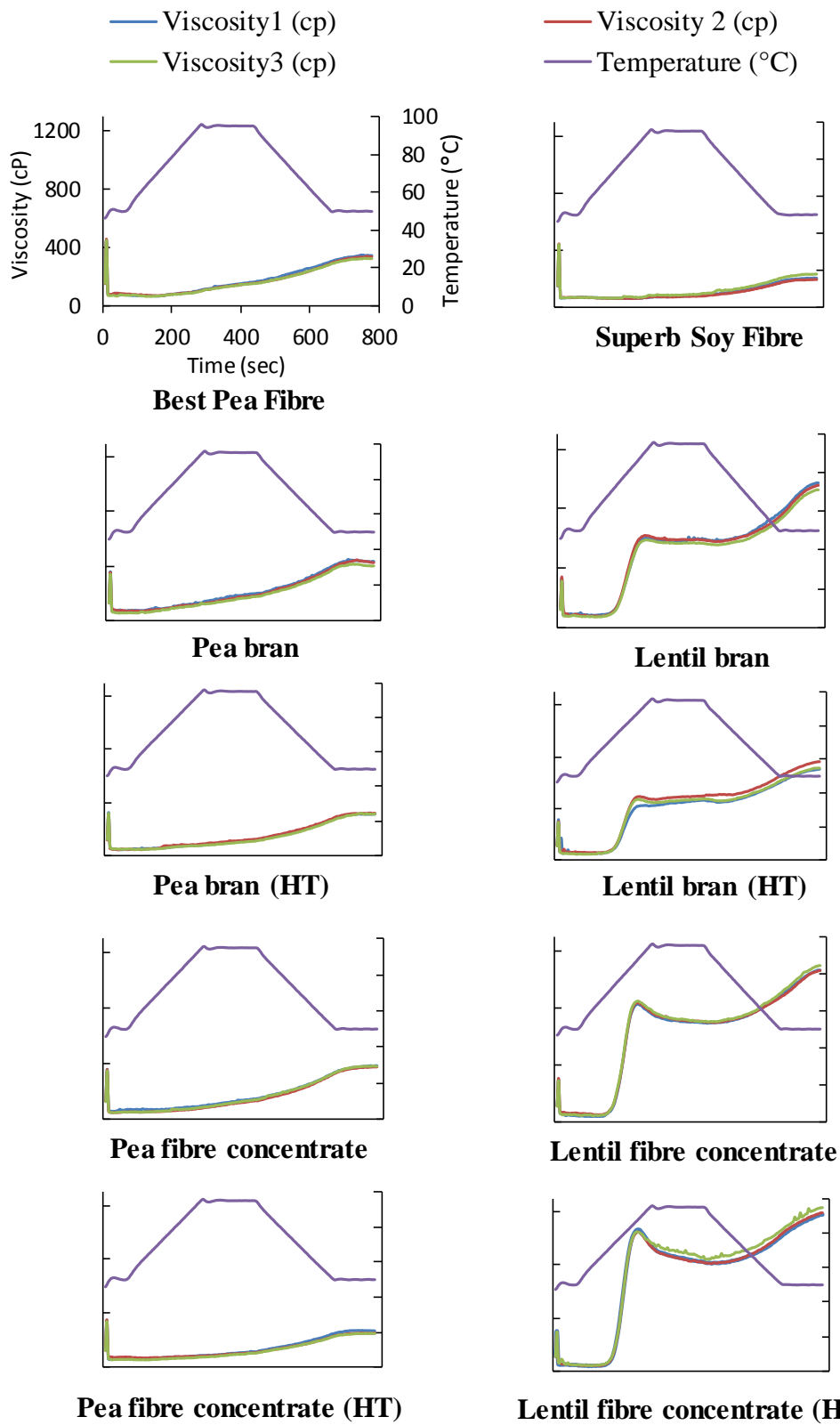


Figure 3-5 Pasting curves of heat treated (HT) and non-HT fibre fractions of yellow pea and red lentil measured by the standard method

Table 3-9 Parameters of pasting properties of heat treated (HT) and non-HT fibre fractions of yellow pea and red lentil (n=3)

Treatment	Peak viscosity (cp)	Final viscosity (cp)	Peak time (min)	Pasting temperature (°C) ^{ns}
Pea bran	n.d.	377.6 ± 64.7 ^{de}	n.d.	n.d.
Pea bran (HT)	n.d.	295.3 ± 15.7 ^{efg}	n.d.	n.d.
Pea fibre conc.	n.d.	412.6 ± 35.5 ^d	n.d.	n.d.
Pea fibre conc. (HT)	n.d.	249.4 ± 22.5 ^{fg}	n.d.	n.d.
Lentil bran	582.1 ± 25.0 ^c	920.3 ± 32.5 ^b	5.2 ± 0.9 ^a	71.0 ± 5.2
Lentil bran (HT)	514.4 ± 33.9 ^c	805.9 ± 70.0 ^c	5.8 ± 0.6 ^a	74.1 ± 0.5
Lentil fibre conc.	898.0 ± 64.4 ^b	1117.8 ± 49.7 ^a	4.1 ± 0.0 ^b	71.7 ± 0.3
Lentil fibre conc. (HT)	1087.4 ± 29.9 ^a	1216.4 ± 15.8 ^a	4.1 ± 0.0 ^b	71.7 ± 0.1
Best Pea Fibre	n.d.	336.3 ± 10.6 ^{def}	n.d.	n.d.
Superb Soy Fibre	n.d.	212.0 ± 19.7 ^g	n.d.	n.d.

Values are presented as mean ± standard deviation

^{a-g}: Means with different superscripts are significantly different ($p < 0.05$)

^{ns}: Means within the same column are not significantly different ($p > 0.05$)

n.d.: not detectable

fibre conc. = fibre concentrate

Generally, pasting curves are used specifically to describe starch-containing products. Peak viscosity means the maximum viscosity obtained during the heating. Pasting temperature refers to the temperature at which the viscosity trace first rise above the baseline during the heating. Final viscosity is the viscosity at the end of the test (Crosbie et al., 2007). Figure 3-5 showed that lentil fibre fractions had a relatively typical pasting curve of starch based ingredients so its pasting parameters such as peak viscosity, final viscosity, pasting time and pasting temperature were listed and compared. However, pea fibre fractions and commercial products showed obviously different pasting characteristics, in which case only their final viscosities were comparable. The difference in the pasting characteristics between lentil and pea fibre fractions mainly came from their different chemical composition. For lentil fibre fractions, lentil fibre concentrate showed significantly higher peak viscosity, final viscosity and shorter peak time than lentil bran because of its higher starch content (17.44% and 14.75%, respectively). Their pasting temperatures were 71.00 °C and 71.70 °C, respectively, without significant difference. The reported data of pasting properties of lentil starch were peak viscosity 7308 mPas, peak temperature 71.9 °C, peak time 4.40 min, final viscosity 6516 mPas (1 mPas = 1 cp) (Joshi et al.,

2013). The dramatically lower values obtained in our results were due to their significantly lower starch content.

Lab-scale hydrothermal treatment had minimal effects on pasting behavior. It only reduced the final viscosity of lentil bran and increased peak viscosity of lentil fibre concentrate without affecting other parameters. Hydrothermal treatment was reported to restrict the granular swelling and decrease amylose leaching of pea and lentil starch (Chung et al., 2009, 2010). This was attributed to their disruption of crystalline structure, increased crystallinity, amylose-lipid interactions and interactions between amylose - amylose and/or amylose - amylopectin chains (Hoover et al., 1994). These changes in starch granules probably could explain the lower final viscosity of HT lentil bran. Instead of the impacts brought by heat treatment, the higher peak viscosity value of HT lentil fibre concentrate was more likely due to its larger starch proportion as mentioned before. The presence of large amounts of dietary fibre in lentil fibre fractions also could influence their pasting properties. Yildiz et al. (2013) observed that adding 2.5 - 20% oat, pea, lemon and apple dietary fibres significantly increased the peak viscosity and final viscosity of wheat starch. They presumed that the dietary fibre could disrupt the amylopectin structure and therefore increase the swelling power of starch. A similar result was also obtained by Li et al. (2016) using β -glucan. The fibre based products, in our case the pea fibre fractions, could also increase the viscosity slightly because of their ability to absorb water. SDF such as pectin, gum (guar, agar, carrageenan, alginates and so on), psyllium and β -glucans had better capacity to increase viscosity and form gels than IDF (Abdul-Hamid et al., 2000; Mudgil et al., 2013). The lowest value in the final viscosity was obtained by Superb Soy Fibre. This was possibly attributed to its lower value in TDF and absence of starch.

c) Pasting properties under bologna cooking condition

The pasting curve of fibre products (Rep1) obtained under bologna cooking condition is shown in Figure 3-6 and related parameters are presented in Table 3-10.

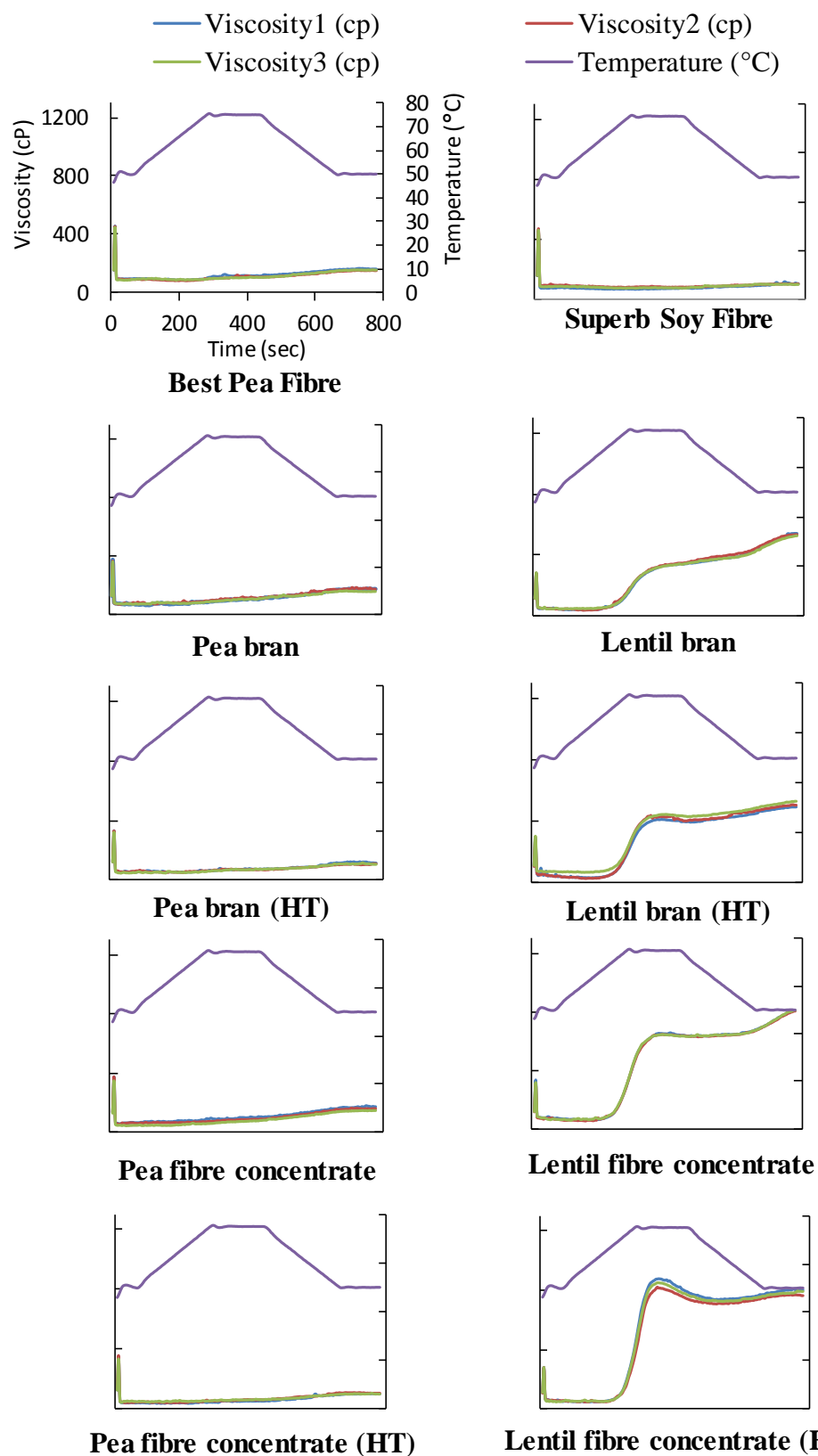


Figure 3-6 Pasting curves of heat treated (HT) and non-HT fibre fractions of yellow pea and red lentil measured under bologna cooking condition.

Table 3-10 Parameters for pasting properties of heat treated (HT) and non-HT fibre fractions of yellow pea and red lentil under bologna cooking condition (n=3)

Treatment	Peak viscosity (cp)	Final viscosity (cp)	Peak time (min)	Pasting temperature (°C)
Pea bran	n.d.	145.6 ± 28.6 ^{de}	n.d.	n.d.
Pea bran (HT)	n.d.	106.8 ± 3.2 ^e	n.d.	n.d.
Pea fibre conc.	n.d.	171.4 ± 10.2 ^d	n.d.	n.d.
Pea fibre conc. (HT)	n.d.	111.2 ± 7.4 ^{de}	n.d.	n.d.
Lentil bran	352.1 ± 19.7 ^c	551.4 ± 19.7 ^b	6.8 ± 0.2 ^a	74.2 ± 1.4 ^a
Lentil bran (HT)	358.9 ± 69.9 ^c	463.3 ± 48.5 ^c	6.7 ± 0.2 ^a	72.8 ± 0.9 ^a
Lentil fibre conc.	675.7 ± 26.3 ^b	844.3 ± 32.5 ^a	6.6 ± 0.1 ^a	70.9 ± 1.3 ^b
Lentil fibre conc. (HT)	871.8 ± 21.5 ^a	798.8 ± 12.9 ^a	5.8 ± 0.0 ^b	70.8 ± 0.1 ^b
Best Pea Fibre	n.d.	156.0 ± 5.6 ^{de}	n.d.	n.d.
Superb Soy Fibre	n.d.	101.3 ± 3.1 ^e	n.d.	n.d.

Values are presented as mean ± standard deviation

^{a-e}: Means with different superscripts are significantly different (p<0.05)

n.d.: not detectable

fibre conc. = fibre concentrate

It could be seen that at the cooking temperature of bologna (75 °C), lentil starch would gelatinize even though it showed much lower peak viscosity and final viscosity compared with the values obtained by standard method with heating temperature at 95 °C. The lower heating temperature restricted the starch granule swelling and amylose leaching. The final viscosity of pea fibre fractions and commercial products were also much lower even though there was still a slight increase in the viscosity. This indicated that heating temperature is an important factor determining the final viscosity. The lower heating temperature will lead to lower final viscosity. Therefore, when incorporating these fibre products into food products, the cooking temperature applied will affect their behavior in the food matrix. To be specific, the swelling ability of starch and dietary fibre might be more restricted when used in bologna than in soup because of the lower cooking temperature.

3.4.4 Correlation coefficients analysis

According to the results of Pearson correlation analysis (Table 3-11), the TDF and IDF had very strong positive relation ($r = 0.999$, $p < 0.01$). The correlation between functional properties and chemical components were shown in this table. It could be seen that water holding capacity

has positive correlation coefficients with TDF and IDF ($r = 0.80$ and 0.79 , respectively, $p < 0.01$), and negative coefficients with starch and fat content ($r = 0.97$ and -0.74 , respectively, $p < 0.01$). Negative correlation was found between oil absorption capacity and starch ($r = -0.65$, $p < 0.01$) and positive correlation was found between oil absorption capacity and SDF ($r = 0.72$, $p < 0.01$). For the hot absorption, it showed very strong positive correlations with TDF and IDF ($r = 0.93$ and 0.94 , respectively, $p < 0.01$) and negative correlations with protein and starch ($r = -0.88$ and -0.88 , respectively, $p < 0.01$). The correlations of final viscosity measured by standard method and bologna cooking method were quite similar. These two parameters were strongly correlated with each other ($r = 0.98$, $p < 0.01$) and positively correlated with starch and negatively correlated with water holding capacity, TDF and IDF (data in Table 3-11).

Table 3-11 Correlation coefficients (r) among data of some chemical components and functional properties of all fibre products (n=30)

	2	3	4	5	6	7	8	9	10	11	12
Chemical component											
1. TDF ¹	1**	0.55**	-0.86**	-0.83**	-0.97**	-0.82**	0.80**	0.27	0.93**	-0.81**	-0.82**
2. IDF ²	1	0.51**	-0.85**	-0.84**	-0.97**	-0.81**	0.79**	0.23	0.94**	-0.80**	-0.81**
3. SDF ³		1	-0.66**	-0.26	-0.54**	-0.58**	0.66**	0.72**	0.35	-0.64**	-0.62**
4. Starch			1	0.44*	0.81**	0.88**	-0.97**	-0.65**	-0.71**	0.97**	0.95**
5. Protein				1	0.82**	0.49**	-0.38*	0.24	-0.88**	0.41*	0.44*
6. Fat					1	0.80**	-0.74**	-0.26	-0.88**	0.77**	0.77**
7. Total phenolics						1	-0.83**	-0.59**	-0.68**	0.90**	0.88**
Functional property											
8. WHC ⁴							1	0.63**	0.67**	-0.93**	-0.92**
9. OAC ⁵								1	0.06	-0.63**	-0.57**
10. HA ⁶									1	-0.62**	-0.63**
11. Std visc ⁷										1	0.98**
12. Bologna visc ⁸											1

** = Correlation is significant at the 0.01 level (2-tailed)

* = Correlation is significant at the 0.05 level (2-tailed)

^{1,2,3} Total/Insoluble/Soluble dietary fibre

⁴Water holding capacity

⁵Oil absorption capacity

⁶Hot absorption

⁷Final viscosity measured by standard method

⁸Final viscosity measured by bologna cooking method

3.5 Conclusions

After milling, lentil fibre fractions showed much finer particles than pea fibre fractions and all of them were coarser than two commercial fibre products. Pea fibre fractions showed much lower protein, fat, starch and total phenolic content but significantly higher TDF than lentil fibre fractions because of less cotyledon contamination. TDF of both varieties predominantly consisted of IDF rather than SDF. All fibre products were very low in oligosaccharides content. The results of this study indicated that the functional properties of all fibre products were determined by their chemical composition and particle size. Products rich in dietary fibre and protein (pea fibre fractions, Best Pea Fibre and Superb Soy Fibre) had better WHC than products with more starch (lentil fibre fractions). More protein content and finer particles might contribute to better OAC, reflected by the higher values found in two commercial fibre products. HA was predominantly determined by the combined effects of swelling of starch and dietary fibre, and protein denaturation. For the pasting properties, products with more starch showed peak viscosity and higher final viscosity than products with more dietary fibre and protein. The final viscosity would be lower when heated at lower temperature because of the restricted swelling capacity of starch and dietary fibre. The two commercial fibre products showed pasting pattern similar to pea fibre fractions. Overall, lab-scale hydrothermal treatment did not affect the chemical composition and functional properties of all fibre products significantly except for reducing the moisture content. The only exception was the increase in protein and starch content and decrease in TDF and total phenolics of lentil fibre concentrate after hydrothermal treatment. Rather than heat effects, we presumed that this reduction resulted from the loss of seed coats during the treatment. The change in its chemical composition also induced the changes in its functional properties. Our results also showed that lab-scale hydrothermal treatment could reduce the peak viscosity and final viscosity of lentil bran probably by restricting the starch granule swelling capacity and amylose leaching.

Hydrothermal treatment is widely used in the food industry, mainly to reduce the microbial load of food products for human consumption and to inactivate enzymes that lower product quality. In some cases, it is also employed to improve the functional properties of food products by denaturing protein and gelatinizing starch to some extent. However, in our study, the lab-scale hydrothermal treatment had no significant effects on the functional properties of pea and lentil fibre fractions, indicating that the chemical composition might be a more important factor in

determining functional properties rather than hydrothermal treatment. More dramatic changes in the functional properties by hydrothermal treatment are likely to be obtained from protein or starch based samples, namely lentil fibre fractions, rather than fibre based ones, namely pea fibre fractions. Therefore, the functionalities of lentil fibre fractions with larger proportion of protein and starch might be improved by modified hydrothermal treatment with increased moisture content and longer treatment time (for example boiling for 1 h). Furthermore, the lab-scale hydrothermal treatment employed in this study was ineffective because it did not inactivate the lipoxygenase. For their further application in food products, especially in meat products, more severe treatment should be applied to prevent any unwanted enzyme activity. In addition, according to the sample preparation, the fibre products were heat treated first and then milled into fine particles for the further test. However, in the real industry, milling usually comes before heat treatment. Therefore, to achieve better effects on food safety and functionality, milling should be arranged before the hydrothermal treatment if the company wants to scale up the production of these fibre products in real factories. Last but not least, based on our analysis, the lentil fibre fractions were contaminated by large amounts of cotyledons. To improve their purity, additional treatments such as air classification or alternative treatments such as using different sieve sizes could be employed or investigated.

3.6 Connection to the next study

The overall goal of this study is to investigate the physicochemical and functional properties of HT and non-HT fibre fractions of yellow pea and red lentil as well as two commercial products. Some methods were chosen to predict their performance in meat systems. In the next study, the HT pea fibre fractions will be used as binders to produce low-fat bologna. The Best Pea Fibre will be used as the reference for comparison because of its similar chemical composition with HT pea fibre fractions according to the results obtained in this study. These results also will provide theoretical explanation for their effects on the physicochemical, functional, textural and sensory properties of finished products.

4. Study 2: Effects of heat treated fibre fractions from yellow pea on processing, textural and sensory properties of low-fat pork bologna

4.1 Abstract

Two levels (1.25% and 2.5%) of Best Pea Fibre and HT pea fibre fractions were utilized to produce low-fat pork bologna products (10% fat) as binders and their chemical composition, textural and sensory properties were evaluated in this study. For raw meat batters, incorporation of fibre products increased ($p<0.05$) the viscosity and higher addition level enhanced this increase. After cooking, bologna with all treatments showed consistent protein and fat content. Adding binders did not change the L^* (lightness) and a^* (redness) value of the bologna but significantly increased ($p<0.05$) the b^* value (yellowness). All the treatments showed very low cook loss ($< 1.0\%$) and no significant differences were found among them. HT pea fibre fractions significantly increased ($p<0.05$) the expressible moisture content compared to control group, indicating reduced water holding ability but they decreased ($p<0.05$) the purge loss of sliced bologna during simulated retail storage. Best Pea Fibre did not significantly change both purge loss and expressible moisture. According to the results of texture profile analysis, low-fat pork bologna with Best Pea Fibre showed higher value in hardness and lower value in adhesiveness ($p<0.05$) compared with the control group. On the contrary, bologna produced with HT pea fibre fractions showed lower ($p<0.05$) hardness, cohesiveness, springiness and chewiness compared with the control and no changes in adhesiveness. Fourteen trained panelists evaluated these bologna products and the results showed that adding Best Pea Fibre did not significantly change the firmness, cohesiveness and foreign flavor in comparison to the control group. Whereas, the scores of these attributes of bologna with HT pea fibre fractions were much lower ($p<0.05$) than the control group. All the fibre products would make the products less juicy and grainier ($p<0.05$) but no changes were found in the overall flavor intensity. For the overall acceptability, the bologna products with Best Pea Fibre and 1.25% HT pea fibre fractions were acceptable to panelists but they disliked the ones with 2.5% HT pea fibre fractions.

4.2 Introduction

It is widely acknowledged that excessive consumption of fat, especially saturated fat and cholesterol, will increase the risk of cardiovascular diseases (Astrup et al., 2011; Sharma et al., 2010). However, fat reduction in food products is controversial. Health is the main reason for consuming low-fat products while unacceptable flavor and taste are the main concerns given for not using them (Girouard et al., 1997). Therefore, the food industry is challenged to develop technology and ingredients used to produce acceptable food products with reduced fat content (Sigman-Grant, 1997). In the meat industry, the fat content is especially important for the quality of final products because it is associated with desirable flavor, texture and functionality (Keeton, 1994). Several ingredients have been developed and used to offset the undesired side effects of fat reduction such as soy and dairy protein, gums and starch, and vegetable oils (Colmenero, 1996).

Field peas (*Pisum sativum* L.) are cool season legumes and grown in large quantity across Canada. They are primarily used for human consumption or as livestock feed (Endres et al., 2016). Pea hull is lightly coloured, tasteless, and very rich in dietary fibre, which makes it an ideal fibre ingredient for food application (Ralet et al., 1993). The use of pea hull fibre in food products started back in 2001 when it was incorporated into pureed foods. Later, the yellow pea fibre was recognized as a novel fibre and allowed to be listed on nutritional labels in Canada in 2006 (Fitzpatrick, 2007). Pea fibre has been used as a functional ingredient to produce low-fat meat products with increased cooking yield and improved texture properties (Anderson & Berry, 2000; Pietrasik & Janz, 2010). However, most of the research is conducted on pea cotyledon fibres not pea hull fibres. Therefore, more scientific research should be carried out on the pea hull fibre for its potential application in meat products.

The purpose of this study is to utilize pea hull fibre (pea fibre fractions in this case) to produce low-fat pork bologna. Their effects on the functional, textural and sensory properties of the final products were investigated. Best Pea Fibre is a commercially available pea hull fibre with similar chemical composition with HT pea fibre fractions (results shown in study 1). Therefore, it was used as a commercial fibre reference in this study.

4.3 Materials and methods

4.3.1 Preparation of low-fat pork bologna with HT fibre fractions from yellow pea

a) Bologna formulation

Fresh boneless pork shoulder picnic was obtained from a commercial slaughter plant (Maple Leaf Foods Inc., Manitoba, Canada) and kept at +1 °C before use. Pork back fat was kept at -30 °C and thawed at +1 °C overnight. Before processing, both of them were ground using a grinder (The Biro MFG. Co. Marblehead, OHIO, USA, Model AFMG-24), through plates with different opening sizes 6.5 mm and 3.9 mm sequentially. The ground meat was kept at +1 °C until processing. Non-meat ingredients except the binder were also used to formulate pork low bologna, including 33.38% ice water, 1.7% salt, 0.29% prague powder (6.4% sodium nitrite, 93.6% sodium chloride, Griffith Laboratories, Scarborough, ON, Canada), 0.2% sodium tripolyphosphate (Unipac Packaging Products Ltd, Edmonton, AB, Canada), 0.1% sodium erythorbate (Unipac Packaging Products Ltd, Edmonton, AB, Canada) and 0.48% Wiener German style seasoning (Hela Spice Canada Inc. Uxbridge, ON, Canada). The HT pea fibre fractions were used as binders in the low-fat pork bologna. They were added at two levels (1.25% and 2.5%) by replacing part of the water. A commercial product, Best Pea Fibre (Best Cooking Pulses Inc. Manitoba, Canada), was used as a reference and incorporated into the meat batter at the same levels. The detailed formulas are listed in Table 4-1.

Table 4-1 Low-fat pork bologna formulations with two levels of pulse fibre-based binders

Binder type	Pork picnic & pork back fat (%) ¹	Ice water (%)	Binder (%wb)	Other ingredients (%) ²
Control (no binder)	63.85	33.38	0	2.77
Best Pea Fibre 1.25%	63.85	32.13	1.25	2.77
Best Pea Fibre 2.5%	63.85	30.88	2.5	2.77
Pea bran (HT) 1.25%	63.85	32.13	1.25	2.77
Pea bran (HT) 2.5%	63.85	30.88	2.5	2.77
Pea fibre conc. (HT) 1.25%	63.85	32.13	1.25	2.77
Pea fibre conc. (HT) 2.5%	63.85	30.88	2.5	2.77

¹: The proportion of pork picnic and back fat added to each batch may vary to achieve the targeted meat protein and fat content of the final products

²: Other ingredients include 1.7% salt, 0.29% prague powder, 0.2% sodium tripolyphosphate, 0.1% sodium erythorbate and 0.48% Wiener German style seasoning

All the dry ingredients were weighed, premixed and kept chilled at +1 °C prior to processing. The meat protein and fat content of the final bologna products were adjusted to 11% (Meat products with a filler must contain no less than 9.5% meat protein and 11% total protein for uncooked product according to Canadian Food Inspection Agency) and 10 % (low-fat bologna products), respectively, and kept consistent for all treatments.

b) Processing procedure of low-fat pork bologna

Three batches of low-fat pork bologna were processed (with meat sourced separately for each replication). For each batch, the different treatments (fibre binder type and level) were processed in random order. The detailed processing procedure is described in the following diagram (Figure 4-1). The processing procedure was carried out with pilot-scale equipment in the meat pilot plant (temperature kept around 4 °C) at the University of Saskatchewan (Saskatoon, SK, Canada). A thermometer was used to check the temperature of the meat batter during the processing, which was maintained below 15 °C.

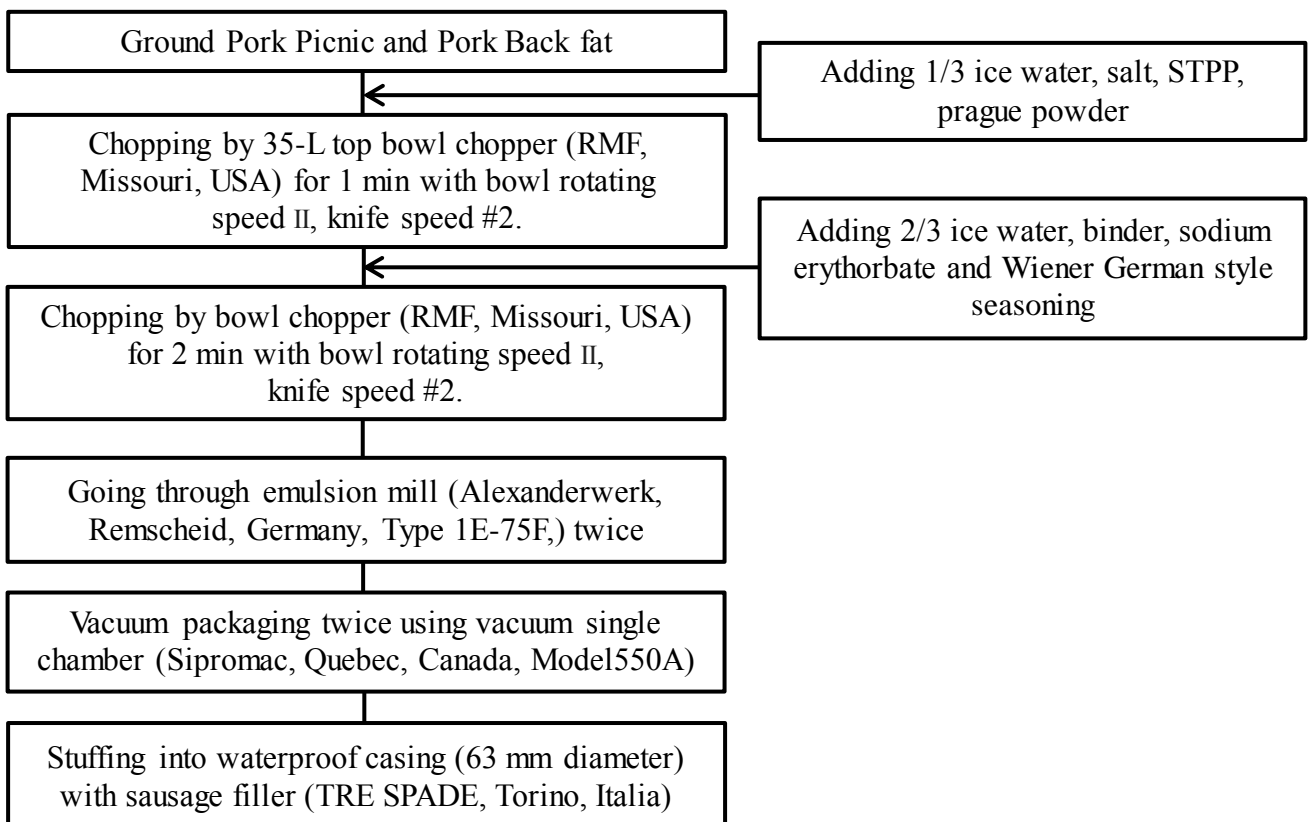


Figure 4-1 Flowchart of processing procedure of low-fat pork bologna products with binders

c) Cooking method

After processing, the bologna products were kept in the +1 °C cooler overnight and cooked the next day in water with Dixie RDTI-3 Retort (DIXIE Canner Co. Athens, Georgia, USA). The bolognas were immersed into the hot water bath preheated to 50 °C and kept for 30 min. Then the water temperature was increased gradually to 60 °C and 70 °C and remained at each temperature for 30 min. At the end, the temperature of water bath was increased to 75 °C and maintained until the internal temperature of bologna reached 72 °C. During cooking, the hot water was agitated by air for heat transfer and thermocouple probes were used to check the temperature of both water bath and bologna products. Temperature changes were monitored by computer. The total cooking time was 2 h approximately. The cooked bologna products were cooled in ice water bath for 1 h and kept in the +1 °C cooler for storage.

4.3.2 Processing properties

a) Cooking loss

The cooking loss of bolognas with different added fibres was measured based on the weights before and after cooking. After chilling at +1 °C cooler overnight, one chub of each treatment was opened, blotted with a paper towel and weighed. Cooking loss was calculated according to the following equation.

$$\text{Cooking loss \%} = \frac{\text{sample weight before cooking} - \text{sample weight after cooking}}{\text{sample weight before cooking}} \times 100 \quad (\text{eq. 4.1})$$

$$\text{Sample weight} = \text{Weight of bologna chub} - \text{weight of casing} - \text{weight of metal clips}$$

b) Viscosity of meat batter

Before stuffing the meat batter into the casing, one cup (~250 mL) of meat batter (~200 g) from each treatment was used to measure the viscosity by a programmable rheometer (Brookfield Engineering Laboratories Inc. Middleboro, MA, USA, Model DV-III+) equipped with #7 spindle at the speed of 10 rpm. The viscosity of the meat batter was recorded at 30 s as well as the temperature.

c) pH of meat batter

The pH values of meat batters were evaluated using a pH meter (Fisher Scientific Accumet,

ON, Canada, Model AR15). About 20 g of sample was placed in the filter bag (Nasco Whirl-Pak, WI, USA). Eighty mL distilled water was added to the bag and blended by the Stomacher Lab-Blender (Seward Ltd, Bury St. Edmunds, UK, Model BA6021) for 3 min. The pH electrode was immersed into the filtered solution and stable value was recorded. All the samples were done in duplicate.

4.3.3 Proximate analysis and pH

a) Moisture

The moisture content of cooked samples was measured according to AOAC method 950.46 (1990). Three to four gram ground sample were dried in a 105 °C oven overnight. After cooling down in dessicator for 1 h, the moisture content was calculated according to the following equation.

$$\text{Moisture content \%} = \frac{\text{sample weight} - \text{dried sample weight}}{\text{sample weight}} \times 100 \quad (\text{eq. 4.2})$$

b) Protein

The protein content of the cooked samples was analyzed by the method mentioned in section 3.3.2 d. The nitrogen conversion factor for meat protein is 6.25. The sample weight used for analysis was around 100 mg.

c) Fat

The crude fat content of each cooked sample was analyzed using AOAC method 960.39a (1990) with slight modification. Around 2.5 g ground sample was weighed into thimble containing around 1 g acid washed sand. After mixing with glass rod, the sample was dried at 105 °C overnight. Fat extraction was carried out by SOXTHERM rapid extraction system (C. Gerhardt GMBH & CO. KG, Germany) using the petroleum ether with programmed procedure (fat extraction at 135 °C for 2 h).

d) Ash

The ash content of cooked samples was measured by AOAC method (1990). Three to four gram sample were weighed and dried at 105 °C overnight. After that, the sample was charred at

550 °C overnight in the furnace.

e) pH

The pH of cooked bologna was measured following the method described in section 4.3.2 c.

4.3.4 Physical and textural properties

a) Cooked bologna sliced for measurement

One bologna chub from each treatment was opened and sliced for measuring the physical and textural properties. The portions sliced for the analysis of different properties were shown in Figure 4-2.

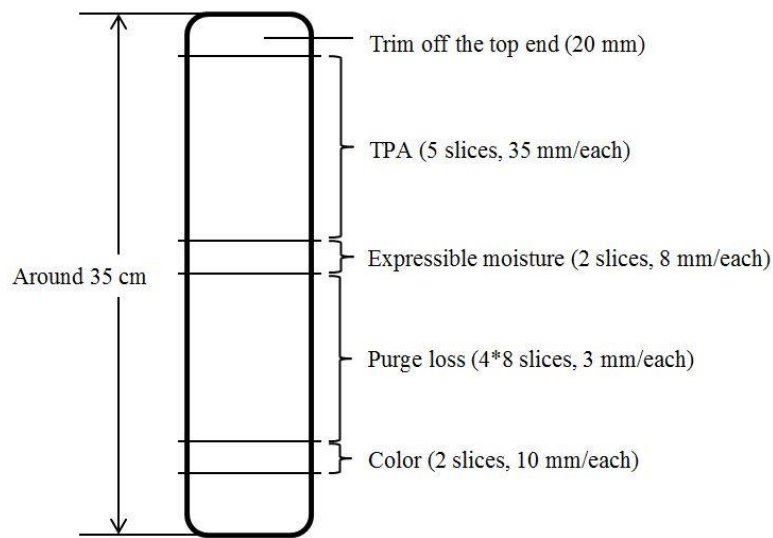


Figure 4-2 Portions of cooked bologna sliced for measuring various properties

b) Colour measurement

The colour of the sliced cooked bologna was measured using a HunterLab Miniscan XE colourimeter (Hunter Associations Laboratory Inc., Reston, VA, USA, Model 45/0L) based on L* (lightness), a* (redness) and b* (yellowness) dimensions with illuminant A and 10 ° observer. All the samples were done in duplicate.

c) Expressible moisture

The expressible moisture was measured using a modified method of Jaurequi et al (1998)

and Foegeding and Ramsey (1986). A cored sample (1.0 - 1.5 g) was placed in the thimble shaped filter papers (Whatman # 3 and # 5 in a 50 mL Falcon plastic tube). After centrifugation for 15 min at 1900 rpm at 4 °C, the expressible moisture was calculated as the percent weight loss from the original sample. Each sample was done in triplicate.

d) Purge loss

The purge loss was measured based on the drip loss during simulated retail storage. Two stacks of 4 slices (3 mm thickness) of bologna were vacuum packaged (50% vacuum) in the pre-weighed vacuum bags by the vacuum single chamber (Sipromac, Quebec, Canada, Model 550A). The weight was recorded and the package was kept upright at 4 °C for storage. The package was opened at 14 days and 28 days and the weight of blotted slices was recorded, respectively. Each sample for each storage period was done in duplicate. The purge loss was calculated as the percentage of weight loss (purge loss) from the initial sample weight.

e) Texture profile analysis

The texture profile analysis was carried out using the method of Unatrakarn (2014) with slight modifications. Five sliced and cored bologna samples (25 mm height and 35 mm diameter) from each treatment were prepared and equilibrated at room temperature for 1 h. The texture profile was characterized by compressing the sample twice to 50% of the sample height (12.5 mm) at a speed of 100 mm/min by the TMS-Pro Texture Press (Food Technology Corp., Rockville, MD, USA) equipped with 250 N capacity load cell. The texture profile was recorded as a force-time curve (Figure 4-3) and analyzed by Texture Lab pro software to calculate the following attributes (Bourne, 2002). Each treatment was done in triplicate.

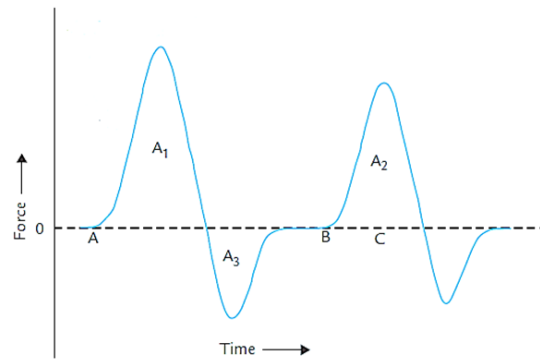


Figure 4-3 A typical force-time curve of textural profile analysis (A_1 , A_2 , A_3 represent the force area of the first and second compression, and the negative force area of the first compression, respectively) (Bourne, 2002 with minor modifications)

- Hardness: the maximum force of the first compression (the height of force peak of the first compression).
- Cohesiveness: extent to which the sample could be deformed before rupture (A_2/A_1 , A_1 and A_2 represent the force area of the first and second compression, respectively).
- Adhesiveness: the work need to pull the compressing plunger away from the sample (A_3 , A_3 is the negative force area of the first compression).
- Springiness: ability of sample to recover its original form after the deforming force is removed.
- Chewiness: the work needed to chew a solid sample to a steady state of swallowing (hardness \times cohesiveness \times springiness).

4.3.5 Sensory evaluation of bologna products by trained panelists

The procedure to conduct sensory evaluation involving human subjects was reviewed and approved by the University of Saskatchewan Research Ethics Board (Beh 07-188). Eighteen panelists were recruited for the sensory evaluation of cooked bologna in the sensory evaluation room at University of Saskatchewan. Before the real experiment, several commercial or formulated bologna samples were used to train the panelists for learning different taste properties. The training was conducted following the procedure of American Meat Science Association (2015).

After training for one month, a screening test was conducted to select potential panelists for the real sensory evaluation experiment. The bologna products used for screening were

formulated according to the experimental parameters and the screening test was conducted for 3 days by serving the same samples with different serving orders. The final panelists were chosen based on their capability to tell the difference in the samples and the repeatability of their results. The final panel consisted of fourteen people including 11 females and 3 males with the age range of 20 to 40 years old. All the panelists were recruited from the Department of Food and Bioproduct Sciences at the University of Saskatchewan.

For sensory evaluation, the bologna products of each treatment were prepared as cubes (12.5 mm × 12.5 mm) and kept in the refrigerator at 4 °C until serving. Four sample cubes of each treatment were served in a small plastic cup with lid to each panelist. Three-digit random numbers were used to represent different samples and all the panelists tasted the bologna samples in different serving order. A total of 7 bologna samples were served on each occasion and a reference sample (the control treatment) was also provided to help panelists evaluate the foreign flavor. The sensory evaluation was conducted in the sensory evaluation room located at the Agriculture building at University of Saskatchewan. This room is equipped with individual booths. Panelists evaluated the samples under the red light to minimize any effect of sample colour. A cup of water, cracker, toothpick, paper towel, pencil and waste cup were also provided along with the bologna samples on the grey tray. For the evaluation, panelists were required to evaluate the different attributes of bologna samples in a given evaluation card (Appendix A) using eight-point structured scales, except that graininess was a six-point scale. The explanation of each attribute was provided in Appendix B.

4.3.6 Statistical analysis

The mean and standard deviation were calculated with triplicate measurements and three replicates for all samples. Data were analyzed by one-way analysis of variance (ANOVA) using the Statistical Package of R software. The significance was declared at $p < 0.05$. Pearson correlation coefficients among all the measured parameters were determined using Statistical Product and Service Solutions (SPSS).

4.4 Results and discussion

4.4.1 Viscosity and pH

The viscosity and pH of processed raw meat batter formulated with fibre products are listed in Table 4-2. There was no significant difference in the temperature and pH values of meat batters from different treatments. The pH values of raw meat batters were higher than the raw pork picnic (5.99 ± 0.14) because of the addition of STPP and other ingredients. Considering the viscosity, the control bologna product showed the lowest viscosity compared with the ones with binders, indicating that adding binders significantly increased the batter viscosity. To be specific, addition of Best Pea Fibre improved the viscosity of meat batter significantly and the increased addition level led to higher viscosity values. For HT pea fibre fractions, binder addition level at 1.25% did not change the raw meat batter viscosity while binder addition level at 2.5% did. The increased viscosity of raw meat batter with binders may be due to following reasons. First, the binder partially replaced the water, therefore reducing the moisture content of meat batter. Second, the binder addition might enhance the water holding capacity of the raw meat batter and increased its viscosity. Similar results were reported by several studies with different fibre products (Choi et al., 2015; Claus & Hunt, 1991). The increased viscosity of low-fat meat batter would benefit some processing procedure, such as stuffing, because it becomes easier to handle (Shand, 2000).

Table 4-2 Effect of binders on the viscosity and pH of raw meat batter (n=3)

Treatment	Viscosity (cP) $\times 10^4$	Temperature ($^{\circ}\text{C}$) ^{ns}	pH ^{ns}
Control	8.53 ± 0.44^d	14.6 ± 0.2	6.28 ± 0.13
Best Pea Fibre 1.25%	10.38 ± 1.09^{bc}	14.6 ± 1.6	6.26 ± 0.18
Best Pea Fibre 2.5%	12.33 ± 0.55^a	16.9 ± 0.7	6.23 ± 0.10
Pea bran (HT) 1.25%	9.19 ± 0.51^{cd}	14.8 ± 1.4	6.24 ± 0.16
Pea bran (HT) 2.5%	11.26 ± 0.11^{ab}	15.7 ± 0.4	6.18 ± 0.12
Pea fibre conc. (HT) 1.25%	9.90 ± 0.91^{bcd}	15.9 ± 1.4	6.25 ± 0.13
Pea fibre conc. (HT) 2.5%	11.61 ± 0.37^{ab}	16.0 ± 0.1	6.21 ± 0.12

Values are presented as mean \pm standard deviation

^{a-b}: Means with different superscripts are significantly different ($p < 0.05$)

^{ns}: Means within the same column are not significantly different ($p > 0.05$)

fibre conc. = fibre concentrate

4.4.2 Proximate analysis and pH

The protein, crude fat, ash, moisture content and pH value of the cooked bologna products are listed in Table 4-3. There was no significant difference in the protein, fat, ash and pH value among all treatments. Cooked bolognas with 2.5% binders showed significantly ($p<0.05$) lower moisture content compared with control group because binders were incorporated to replace the water. The raw pork picnic used for bologna production contained $18.96 \pm 0.40\%$ protein and $14.57 \pm 1.02\%$ fat. The protein and fat content of final cooked bologna products was around 12% and 9%, respectively, which were a little different with our original target. The explanation for the difference was that the thermogravimetric moisture analyzer (OHAUS, Switzerland, Model MB45) employed for measuring the fat and moisture content of the raw pork picnic before processing is not as precise as chemical methods, but useful for its fast measurement. Even so, the key consideration is the consistent protein and fat content for all treatments. According to Canadian regulation, the cooked bologna with a filler should contain no less than 9.5% meat protein and 11% total protein (Government of Canada, 2016). Therefore, our products meet this requirement.

Table 4-3 Proximate composition and pH of cooked bologna products with binders (n=3)

Treatment	Moisture (%)	Protein (%) ^{ns}	Fat (%) ^{ns}	Ash (%) ^{ns}	pH ^{ns}
Control	75.84 ± 0.34^a	12.36 ± 0.35	8.42 ± 0.40	2.79 ± 0.09	6.43 ± 0.16
Best Pea Fibre 1.25%	75.27 ± 0.27^a	11.89 ± 0.29	8.92 ± 0.60	2.80 ± 0.05	6.43 ± 0.09
Best Pea Fibre 2.5%	72.64 ± 0.51^b	12.02 ± 0.18	9.45 ± 0.59	2.84 ± 0.06	6.47 ± 0.03
Pea bran (HT) 1.25%	74.94 ± 0.20^a	12.13 ± 0.16	8.84 ± 0.20	2.80 ± 0.04	6.47 ± 0.02
Pea bran (HT) 2.5%	72.51 ± 0.20^b	12.08 ± 0.28	9.60 ± 0.20	2.84 ± 0.01	6.46 ± 0.02
Pea fibre conc. (HT) 1.25%	74.79 ± 0.38^a	12.10 ± 0.34	8.98 ± 0.56	2.81 ± 0.02	6.49 ± 0.03
Pea fibre conc. (HT) 2.5%	72.93 ± 0.72^b	12.31 ± 0.18	9.27 ± 0.85	2.85 ± 0.04	6.46 ± 0.03

Values are presented as mean \pm standard deviation

^{a-b}: Means with different superscripts are significantly different ($p<0.05$)

^{ns}: Means within the same column are not significantly different ($p>0.05$)

fibre conc. = fibre concentrate

4.4.3 Colour measurement

The colour of the cooked bologna with different binders is shown in Table 4-4.

Table 4-4 Effect of binders on the colour of cooked bologna products (n=3)

Treatment	CIE colour		
	L* ^{ns}	a* ^{ns}	b*
Control	67.40 ± 0.95	16.64 ± 0.26	13.75 ± 0.47 ^c
Best Pea Fibre 1.25%	67.89 ± 1.21	16.53 ± 0.30	14.28 ± 0.31 ^{abc}
Best Pea Fibre 2.5%	68.51 ± 0.91	16.14 ± 0.36	15.06 ± 0.10 ^a
Pea bran (HT) 1.25%	67.17 ± 1.17	16.27 ± 0.50	14.13 ± 0.29 ^{bc}
Pea bran (HT) 2.5%	67.24 ± 0.68	16.05 ± 0.37	14.96 ± 0.25 ^a
Pea fibre conc. (HT) 1.25%	67.30 ± 0.72	16.89 ± 0.26	14.12 ± 0.11 ^{bc}
Pea fibre conc. (HT) 2.5%	67.27 ± 0.75	16.45 ± 0.20	14.70 ± 0.21 ^{ab}

Values are presented as mean ± standard deviation

^{a-c}: Means with different superscripts are significantly different ($p < 0.05$)

^{ns}: Means within the same column are not significantly different ($p > 0.05$)

fibre conc. = fibre concentrate

Meat colour is one of the most important factors affecting consumers' decision when they purchase meat products. It is mainly determined by an oxygen-binding protein, namely myoglobin. In addition, the pH and fat content of meat products, processing procedure, such as packaging, and the ingredients incorporated into the meat products, such as the binders in this study, could also influence the colour of final products (King et al., 2006). In Table 4-4, no significant difference was found in L* (lightness) and a* (redness) among all the treatments, illustrating that adding binders at the levels used had no significant effects on these colour values. For b* (yellowness), adding the binders at 1.25% level did not change the b* compared with control group. However, when the binders were added at 2.5% level, the b* of bolognas with all binders were higher than control group. This presumably resulted from the yellow colour of pea fibre products. Also, the L*, a* and b* values of cooked bolognas with binders were not significantly different with each other at the same addition level which means that pea fibre fractions from AGT Food and Ingredients company showed the similar impacts on the bologna colour with the commercial product Best Pea Fibre. Increased b* was reported by Choi et al. (2015) when they included 2% rice bran into frankfurters. Same changes in b* value were also observed in the low-fat bologna produced with dietary fibres from oat, pea and sugar beet pulp (Claus & Hunt, 1991). They also reported that the bologna made with pea fibre had the same a* value with the control group due to its light colour.

4.4.4 Cook loss, expressible moisture and purge loss

The cook loss, expressible moisture and purge loss of cooked bologna with various binders are shown in Table 4-5. There was almost no cook loss for all the treatments (less than 1%). Considering expressible moisture, it could be seen that the addition of Best Pea Fibre at two levels did not significantly change the expressible moisture content compared with the control group. In contrast, most bologna with HT pea fibre fractions had higher expressible moisture content than control group except for the one with 1.25% HT pea fibre concentrate. For purge loss, sliced bologna products were kept for 2 and 4 weeks to simulate retail packaging condition and the drip loss was calculated. The result showed that prolonged storage time would not influence the purge loss significantly. Adding the Best Pea Fibre at both levels slightly decreased the purge loss but the decrease was not statistically significant when compared with the control group. The same thing happened to HT pea fibre fractions at 1.25% addition level. The lowest values of purge loss were obtained by bologna products with 2.5% addition of HT pea fibre fractions, suggesting a significant improvement on the water holding properties during the storage compared with the control group.

Table 4-5 Effects of binders on the cook loss, expressible moisture and purge loss of cooked bologna products (n=3)

Treatment	Cook loss (%) ^{ns}	Expressible moisture (%)	Purge loss (%)	
			2 weeks	4 weeks
Control	0.69 ± 0.17	14.98 ± 0.39 ^{bc}	2.33 ± 0.22 ^a	2.71 ± 0.38 ^a
Best Pea Fibre 1.25%	0.70 ± 0.12	13.78 ± 1.14 ^c	1.46 ± 0.40 ^{ab}	2.04 ± 0.56 ^{ab}
Best Pea Fibre 2.5%	0.59 ± 0.10	12.27 ± 0.74 ^c	1.25 ± 0.10 ^{ab}	1.81 ± 0.15 ^{ab}
Pea bran (HT) 1.25%	0.62 ± 0.13	18.57 ± 1.14 ^a	1.54 ± 0.61 ^{ab}	1.97 ± 0.65 ^{ab}
Pea bran (HT) 2.5%	0.54 ± 0.01	19.76 ± 1.88 ^a	0.96 ± 0.18 ^b	1.34 ± 0.25 ^b
Pea fibre conc. (HT) 1.25%	0.65 ± 0.01	18.21 ± 1.37 ^{ab}	1.24 ± 0.20 ^{ab}	1.76 ± 0.48 ^{ab}
Pea fibre conc. (HT) 2.5%	0.65 ± 0.13	19.27 ± 1.21 ^a	0.98 ± 0.31 ^b	1.28 ± 0.26 ^b

Values are presented as mean ± standard deviation

^{a-c}: Means within a column with different letters are significantly different ($p < 0.05$)

^{ns}: Means within a column are not significantly different ($p > 0.05$)

fibre conc. = fibre concentrate

Water holding capacity refers to the ability of meat protein systems to hold excess water under different conditions. Cooking loss, expressible moisture and purge loss are the three main

properties used to evaluate the water holding capacity of cooked bologna. To be specific, the cook loss is the weight loss under the cooking condition, which not only associates with water holding capacity, but also relates to the oil holding capacity. Expressible moisture usually refers to the liquid squeezed out of the emulsion system by the external force, such as the centrifugation in this study. Purge loss, also called purge drip, is the liquid loss under no other force except for gravity (Jauregui et al., 1981). Compared with expressible moisture, cooking loss and purge loss are two properties more important for manufacturers because they directly relate to the production cost and the quality of retail products (the bologna products are usually sliced and vacuum packaged for selling in the market). Generally, incorporation of binders with high water holding capacity such as starch and fibre can significantly improve the water holding capacity of bologna products. It was reported that adding three different types of dietary fibre at 0.5% (barley beta-glucan concentrate, potato fibre and cellulose) to the Tunisian beef sausage effectively decreased the cook loss and improved the water holding capacity (Ktari et al., 2014). Similar results were also obtained by Pietrasik and Janz (2010). These authors observed that adding 4% commercial pea fibre (Uptake 80) led to an increase in the cook yield with a concomitant decrease in the expressible moisture and purge loss. The pea fibre has also been used in high fat ground beef (40% and 50% fat content) to achieve a better cooking yield and fat retention even though it was heated to a relatively high internal temperature (~90 °C) (Anderson & Berry, 2001). The increased cooking loss and reduced purge loss of low-fat beef bologna were also reported by including oat and pea fibre (Claus & Hunt, 1991). In this study, even though the expressible moisture could not be effectively reduced, the significant reduction in the purge loss still illustrated that both Best Pea Fibre and HT pea fibre fractions could improve the water holding capacity of the bologna. This observation can be explained by the reduced moisture content and the high water holding capacity of fibre products.

4.4.5 Texture profile analysis

The textural attributes of bologna products with different treatments were analyzed by the instrumental Texture Profile Analysis and the results are shown in Table 4-6.

Table 4-6 Effects of binders on textural properties of cooked bologna (n=3)

Treatment	Textural profile analysis				
	Hardness (N)	Adhesiveness (N)	Cohesiveness	Springiness (%)	Chewiness (N mm)
Control	96.65 ± 9.74 ^b	-0.59 ± 0.05 ^{ab}	0.52 ± 0.02 ^a	79.23 ± 0.51 ^a	555.65 ± 75.08 ^a
Best Pea Fibre 1.25%	106.37 ± 5.26 ^{ab}	-0.77 ± 0.03 ^{bc}	0.52 ± 0.01 ^a	79.97 ± 0.56 ^a	618.29 ± 48.28 ^a
Best Pea Fibre 2.5%	121.44 ± 8.72 ^a	-0.89 ± 0.05 ^c	0.51 ± 0.01 ^a	78.54 ± 0.71 ^a	686.88 ± 71.47 ^a
Pea bran ¹ 1.25%	70.02 ± 12.49 ^c	-0.65 ± 0.05 ^{ab}	0.40 ± 0.04 ^b	73.16 ± 1.70 ^b	283.69 ± 84.87 ^b
Pea bran ¹ 2.5%	47.95 ± 1.09 ^{cd}	-0.58 ± 0.11 ^a	0.26 ± 0.01 ^c	58.25 ± 0.97 ^c	99.99 ± 5.38 ^c
Pea fibre conc. ¹ 1.25%	63.61 ± 6.83 ^{cd}	-0.59 ± 0.08 ^{ab}	0.35 ± 0.02 ^b	69.55 ± 1.69 ^b	221.38 ± 39.60 ^{bc}
Pea fibre conc. ¹ 2.5%	47.02 ± 6.85 ^d	-0.62 ± 0.07 ^{ab}	0.25 ± 0.01 ^c	56.05 ± 3.76 ^c	91.73 ± 24.68 ^c

Values are presented as mean ± standard deviation.

^{a-d}: Means within a column with different letters are significantly different ($p < 0.05$).

^{ns}: Means within a column are not significantly different ($p > 0.05$).

¹: All fibre fractions are hydrothermally treated.

fibre conc. = fibre concentrate

For hardness, bologna with 2.5% Best Pea Fibre had firmer (harder) texture than the control group. Incorporating HT pea fibre fractions at both levels apparently reduced the hardness of bologna products but increased addition level did not significantly reduce the hardness more. No significant difference was found in the adhesiveness among all the bologna products except for the one with 2.5% Best Pea Fibre which had the lowest value. In terms of the cohesiveness, springiness and chewiness, addition of different binders would induce similar changes among all the treatments. To be specific, on one hand, including Best Pea Fibre at both levels did not change these properties significantly when compared with the control sample. On the other hand, bologna products with two levels of HT pea fibre fractions showed lower values in all the attributes than the control group. Moreover, increased addition level led to further reduction in these attributes except for the chewiness of bologna with 2.5% HT pea fibre concentrate.

Improved textural properties have been reported by Pietrasik and Janz (2010) when they incorporated pea fibre into low-fat bologna. Their results showed bologna with 4% pea fibre had higher values in hardness, cohesiveness and chewiness than the control group. Conversely, reduction in these properties was also observed by Ktari et al. (2014) with three different fibre products including beta-glucan, cellulose and potato fibre. Both improved and impaired textures of bologna or sausages including dietary fibre were reported. Many reasons have been suggested

for explaining these opposite results. For example, the difference in the amount and in the type (SDF/IDF) of fibre, the way they are added into the meat products (gel/powder, replacing the meat/water), the difference in the chemical composition of both binder and meat batter, which would lead to the different protein/fat/water ratio and ultimately affect the meat matrix structure (Álvarez et al., 2013; Choi et al., 2015; Ktari et al., 2014; Pietrasik & Janz, 2010). In this study, the low fat bologna containing the binders theoretically should have a harder texture in comparison to the control group formulated with higher moisture content. This did apply to the ones with Best Pea Fibre, but not for the ones with HT pea fibre fractions, which contrarily created much softer texture. The impacts brought by the Best Pea Fibre and HT pea fibre fractions on the bologna texture were quite different even though they had similar chemical composition and origin. The possible explanations could be their difference in the particle size and enzyme activity. Finer particles of Best Pea Fibre than HT pea fibre fractions might achieve better mixture of binders and meat batter. The more exposed surface area might also favor its interaction with meat fat granules and proteins, and stabilize the emulsion system, which ultimately lead to the better texture after cooking. Another factor should be taken into consideration is the relatively high lipoxygenase activity of HT pea fiber fractions (data shown in study 1). The presence of lipoxygenase might trigger lipid oxidation and protein oxidation of meat products, leading to the decrease in protein solubility and protein polymerization. All these changes might ultimately affect their textural attributes (Falowo et al., 2014). The unknown processing procedure for Best Pea Fibre might also be responsible for its different impacts on the meat matrix structure.

4.4.6 Sensory evaluation by trained panelists

The sensory properties of the cooked bologna products with all treatments were evaluated by a group of trained panelists. In addition to confirming the results of some textural traits measured by instrumental methods, such as hardness and cohesiveness, the trained panelists could also give relatively objective opinions about other attributes including juiciness, graininess, overall flavor intensity and foreign flavor. These properties were usually difficult to be measured by instruments. Additionally, since the training period was relatively short, these panelists may be considered as informed consumers, therefore, the overall acceptability was also evaluated to see if these bologna products have the potential to be developed into commercial products. The results of sensory evaluation are shown in Table 4-7.

Table 4-7 Effects of binders on the sensory properties of cooked bologna evaluated by trained panelists (n=3)

Treatment	Sensory properties						
	Firmness	Cohesiveness	Juiciness	Graininess	Overall flavor intensity ^{ns}	Foreign flavor	Overall acceptability
Control	5.7 ± 0.4 ^a	5.6 ± 0.3 ^a	5.5 ± 0.0 ^a	1.3 ± 0.1 ^d	5.4 ± 0.1	7.7 ± 0.1 ^a	6.2 ± 0.1 ^a
Best Pea Fibre 1.25%	6.0 ± 0.3 ^a	5.8 ± 0.2 ^a	5.3 ± 0.0 ^{ab}	1.4 ± 0.1 ^{cd}	5.2 ± 0.0	7.6 ± 0.1 ^a	6.2 ± 0.3 ^a
Best Pea Fibre 2.5%	6.4 ± 0.3 ^a	5.9 ± 0.2 ^a	5.1 ± 0.1 ^{bc}	1.6 ± 0.0 ^c	5.3 ± 0.4	7.3 ± 0.5 ^{ab}	5.8 ± 0.2 ^a
Pea bran (HT) 1.25%	4.1 ± 0.4 ^b	4.4 ± 0.4 ^b	4.9 ± 0.0 ^c	2.3 ± 0.1 ^b	5.6 ± 0.2	6.2 ± 0.5 ^{cd}	4.5 ± 0.3 ^b
Pea bran (HT) 2.5%	3.1 ± 0.3 ^c	3.4 ± 0.2 ^c	4.2 ± 0.2 ^d	3.3 ± 0.1 ^a	5.2 ± 0.1	4.6 ± 0.3 ^e	3.7 ± 0.2 ^c
Pea fibre conc. (HT) 1.25%	4.3 ± 0.1 ^b	4.4 ± 0.3 ^b	4.9 ± 0.2 ^c	2.4 ± 0.0 ^b	5.5 ± 0.3	6.7 ± 0.2 ^{bc}	4.5 ± 0.1 ^b
Pea fibre conc. (HT) 2.5%	3.3 ± 0.4 ^c	3.6 ± 0.4 ^{bc}	4.2 ± 0.0 ^d	3.3 ± 0.1 ^a	5.1 ± 0.1	5.8 ± 0.2 ^d	3.9 ± 0.2 ^c

Values are presented as mean ± standard deviation

^{a-e}: Means within a column with different letters are significantly different ($p < 0.05$)

^{ns}: not significant ($p > 0.05$)

fibre conc. = fibre concentrate

Firmness: 8 = Extremely firm, 1 = Extremely soft

Cohesiveness: 8 = Extremely cohesive, 1 = Extremely brittle

Juiciness: 8 = Extremely juicy, 1 = Extremely dry

Graininess: 6 = Extremely grainy, 1 = Not detectable

Overall flavor intensity: 8 = Extremely intense, 1 = Extremely bland

Foreign flavor: 8 = No foreign flavor, 1 = Extremely intense foreign flavor

Overall acceptability: 8 = Like extremely, 1 = Dislike extremely

In terms of firmness, the highest value was obtained by control group and bologna made with Best Pea Fibre. Adding Best Pea Fibre did not significantly affect the firmness of bologna products. In contrast, the bologna products with HT pea fibre fractions showed a softer texture and increased addition level led to much softer products. This result was similar with the results obtained from the texture profile analysis even though not exactly the same.

The cohesiveness of the bologna products with two levels of Best Pea Fibre did not differ from the control group. However, bologna products with HT pea fibre fractions showed lower scores in cohesiveness. These results also corresponded with the results obtained by texture profile analysis except that the panelists could not distinguish the difference between two levels of HT pea fibre concentrate as was shown by the instrumental TPA.

In terms of juiciness, the control sample and bologna with 1.25% Best Pea Fibre received the highest score, which presumably resulted from its higher moisture content. When including 2.5% Best Pea Fibre, the score for juiciness was significantly lower than the control group. Perception of juiciness for bologna with either level of HT pea fibre fractions with scores indicated “slightly dry”. Increased addition level of HT pea fibre fractions significantly decreased the score for juiciness. A possible solution would be adding more water to offset the loss of juiciness.

The graininess was evaluated to test if the panelists could recognize the particulate nature of the flour or hull particles in the bologna products. In Table 4-7, it was clear to see that adding fibre products significantly increased the score of graininess for all treatment except for the 1.25% Best Pea Fibre in comparison to the control group. Increased addition level resulted in significantly higher scores for HT pea fibre fractions but not for Best Pea Fibre. Compared with HT pea fibre fractions, the amount of graininess perceived in Best Pea Fibre was much less. This might be attributed to its finer particles.

For the bologna flavor, the overall flavor intensity was not affected by adding different binders. However, the panelists could recognize the binder addition, which was supported by the different scores for the foreign flavor. Bologna products containing HT pea fibre fractions had significantly lower scores in foreign flavor compared with the control group and increased addition level led to even lower scores. However, they could not tell the difference between the control group and the samples with Best Pea Fibre, meaning that Best Pea Fibre brings little foreign flavor to the bologna products. The sample with the most foreign flavor (lowest score)

was the bologna with 2.5% HT pea bran. This possibly resulted from its relatively higher contamination with pea cotyledon than HT pea fibre concentrate. Also, more lipid oxidation induced by higher LOX activity might be the reason for the strong off-flavor in the bologna.

In this study, we have set 4.5 as the threshold value for acceptable products. Products with score higher or equal to 4.5 were on the acceptable side of the scale. On the contrary, score lower than 4.5 means that panelists disliked these products. According to the results, it could be seen that control group and bologna products including both levels of Best Pea Fibre were equally liked. The bologna products with 1.25% HT pea fibre fractions were also acceptable to panelists but less than the control group and bologna with Best Pea Fibre. However, the panelists disliked the bologna products made with 2.5% HT pea fibre fractions possibly due to their softer and brittle texture, and strong foreign flavor.

Overall, incorporating Best Pea Fibre as the binder at two levels (1.25% and 2.5%) into low-fat pork bologna products did not significantly change most of their attributes except slight changes in graininess and juiciness. However, its addition would make the bologna products firmer and improve its nutrient value by increasing the fibre content (1% to 2% in this study). According to Health Canada guidelines, food products with a minimum of 2 g of dietary fibre per serving could claim “source of fibre” products. With a serving size of 100 g of bologna (recommended serving size by CFIA), bologna product with 2.5% Best Pea Fibre could provide 2% dietary fibre per serving and therefore could be labelled as a “source of fibre” product.

Even though the HT pea fibre concentrate could provide more dietary fibre (around 0.2%) than Best Pea Fibre but its adverse effects on the bologna texture, such as reduced firmness, cohesiveness and juiciness, and detectable graininess and foreign flavor, would make them less attractive to the consumers. Similar results were also observed by Claus and Hunt (1991). According to the evaluation of experienced panelists in their study, addition of 2% pea fibre did not increase the hardness and cohesiveness of low-fat beef bologna but lowered the scores in graininess (more grainy) and juiciness in comparison to the low-fat control group. Apart from the fibre addition, they suggested that more detectable graininess could also result from the lower juiciness in the products because of less fibre hydration. More work should be done to minimize the foreign flavor and understand why products made with HT pea fibre fractions have softer texture than Best Pea Fibre.

4.4.7 Correlation coefficients analysis

There were many significant correlations between different parameters according to Pearson correlation analysis shown in Table 4-8. Among them, expressible moisture was negatively correlated with hardness and cohesiveness ($r = -0.89$ and -0.85 , respectively, $p < 0.01$). For the textural profile analysis, any pair of two parameters measured showed significantly correlations except for adhesiveness. Hardness and cohesiveness were positively correlated ($r = 0.94$, $p < 0.01$). Also, TPA hardness and cohesiveness measured had very strong positive correlations with firmness and cohesiveness obtained by sensory evaluation ($r = 0.95$, $p < 0.01$), indicating that the instrument could correctly predict the responses of panelists. For the other sensory properties, juiciness was negatively correlated with graininess ($r = -0.93$, $p < 0.01$). The overall acceptability showed very strong correlations with all the other sensory properties except overall flavor intensity.

Table 4-8 Correlation coefficients among data of some functional properties, instrumental textural parameters and sensory parameters of low-fat pork bologna with HT pea fibre fractions and Best Pea Fibre (n=21)

	2	3	4	5	6	7	8	9	10	11	12	13
Functional properties												
1. Expressible moisture	-0.89**	0.77**	-0.85**	-0.77**	-0.90**	-0.92**	-0.90**	-0.74**	0.83**	0.01	-0.77**	-0.86**
Textural profile analysis (TPA)												
2. Hardness	1	-0.69**	0.94**	0.89**	0.99**	0.95**	0.94**	0.79**	-0.89**	0.07	0.82**	0.89**
3. Adhesiveness		1	-0.54*	-0.48*	-0.66**	-0.63**	-0.60**	-0.33	0.48*	0.05	-0.41	-0.48*
4. Cohesiveness			1	0.97**	0.96**	0.94**	0.95**	0.92**	-0.98**	0.21	0.89**	0.96**
5. Springiness				1	0.90**	0.91**	0.92**	0.94**	-0.96**	0.32	0.87**	0.91**
6. Chewiness					1	0.95**	0.95**	0.83**	-0.92**	0.05	0.85**	0.93**
Sensory evaluation												
7. Firmness						1	0.99**	0.85**	-0.93**	0.13	0.90**	0.95**
8. Cohesiveness							1	0.88**	-0.94**	0.13	0.90**	0.96**
9. Juiciness								1	-0.97**	0.28	0.90**	0.92**
10. Graininess									1	-0.23	-0.92**	-0.96**
11. Overall flavor intensity										1	0.18	0.13
12. Foreign flavor											1	0.92**
13. Overall acceptability												1

** = Correlation is significant at the 0.01 level (2-tailed)

* = Correlation is significant at the 0.05 level (2-tailed)

4.5 Conclusions

In this study, HT pea fibre fractions were utilized to produce low-fat pork bologna and their physicochemical, functional, textural and sensory properties were evaluated. The results indicate that adding HT pea fibre fractions increased the yellowness of bologna without affecting its lightness and redness. All bologna products with HT pea fibre fractions showed very low cooking loss and significantly lower purge loss but their expressible moisture content were much higher than the control group. For the textural profile analysis, adding HT pea fibre fractions significantly decreased the hardness and cohesiveness. Increased fibre addition level produced softer and less cohesive bologna products. These were confirmed by the results obtained by sensory evaluation with fourteen panelists. In addition, the panelists also perceived the bologna products with HT pea fibre fractions as less juicy, grainier and with more foreign flavor even though they did not notice any difference in the overall flavor intensity. The panelists found the bologna products with 1.25% HT pea fibre fractions slightly acceptable but they disliked the ones with 2.5% addition.

The benefit of adding the fibre products was mainly to produce more nutritious meat products. However, the drawbacks such as softer and grainy textures and noticeable foreign flavor would impair their appeal to consumers. On the contrary, we observed that the commercial product Best Pea Fibre behaved very differently in comparison with HT pea fibre fractions. It actually improved the texture of low fat bologna with less grainy and foreign flavor even though its chemical composition was very close to HT pea bran. We presumed that the difference might be due to its finer particles, lower lipoxygenase activity and unknown purification procedure. Also, the higher lipoxygenase activity found in HT pea fiber fractions (data present in study 1) might be responsible for its stronger foreign flavor because it can induce lipid oxidation.

For the further improvement of pea fibre fractions, milling the products to a much finer particle size is highly recommended. Also, changing the SDF/IDF ratio by some treatments such as enzyme-micronization (Wen et al., 2017) might be an alternative way to change their functionality even though the product expense will be increased. Inactivating the lipoxygenase by more severe heat treatment is necessary. Furthermore, pea fibre fractions could be used in combination with other functional ingredients such as pea protein to achieve better functionality and lower the cost of those ingredients (seed coat was much cheaper and easy to get). Last but not least, even though the pea fibre fractions did not work very well in the bologna products,

their application in other products is worth investigation.

4.6 Connection to the next study

According to the results obtained in this study, adding different levels of HT pea fibre fractions as well as Best Pea Fibre into low-fat pork bologna affected their functional, textural and sensory properties. The fibre fractions used in this study contains relatively high fibre content (results shown in study 1). Therefore, these effects are mainly determined by the dietary fibre. However, for other pulse crops, such as lentil, fibre fractions obtained by dehulling usually contain large quantities of cotyledons (results shown in study 1). Their different chemical composition possibly affects their performance when incorporated into meat products. Therefore, in the next study, HT lentil fibre fractions were used to produce low-fat pork bologna using the same procedure. HT lentil fibre fractions were added at the same levels as HT pea fibre fractions and processed using the same procedure for the later comparison across different studies. Superb Soy Fibre will be used as the reference sample because of their similar dietary fibre content.

5. Study 3: Effects of heat treated fibre fractions from red lentil on processing, textural and sensory properties of low-fat pork bologna

5.1 Abstract

In this study, heat treated (HT) lentil fibre fractions and Superb Soy Fibre were incorporated into low-fat pork bologna at two levels (1.25% and 2.5%). Their physicochemical, functional, textural and sensory properties were evaluated. Including the fibre products significantly increased ($p<0.05$) the viscosity of formulated raw meat batter except for HT lentil fibre fractions at 1.25% addition level. The pH was not affected by the binder addition. For the proximate analysis, cooked bologna with all treatments contained 12.29 - 13.03% protein, 8.88 - 9.29% fat and 2.79 – 2.89% ash without significant difference. Including more fibre products reduced ($p<0.05$) the moisture content due to the reduced added water. Considering the colour characteristics, including 2.5% HT lentil fibre fractions significantly decreased ($p<0.05$) L* value (lightness) and all the fibre products significantly increased ($p<0.05$) b* value (yellowness) except for 1.25% Superb Soy Fibre and 1.25% HT lentil fibre concentrate. All the bologna products showed low cook loss (less than 0.5%). Only bologna with 2.5% Superb Soy Fibre had reduced ($p<0.05$) expressible moisture content compared with the control group. Reduction in purge loss was observed in all treatments except for 1.25% HT lentil bran. For textural attributes, adding 2.5% Superb Soy Fibre increased ($p<0.05$) hardness and chewiness without significantly changing adhesiveness, cohesiveness and springiness while including HT lentil fibre fractions did not affect most of the textural attributes. In sensory evaluation, all fibre products had no effects on the overall flavor intensity but the panelists could recognize binder addition reflected by the increased scores ($p<0.05$) in graininess and decreased scores ($p<0.05$) in juiciness and foreign flavor. Even so, bologna products with all treatments were evaluated as acceptable products, indicating that they have the potential to be developed into commercial products with delivering up to 1.4 gram total dietary fibre per serving (100 gram) to consumers.

5.2 Introduction

Lentil (*Lens culinaris*) is one of the most important pulse crops in the world and used primarily as human food (Singh et al., 1992). Currently, Canada is the largest exporter of lentils in the global pulse market and 99% of Canada's lentils are grown in Saskatchewan (Pulse Canada, 2016b). The use of lentil seed coat in food products is limited because of the following reasons. First of all, compared with pea seed coat, it is more difficult to separate lentil seed coat with high purity only by dehulling because of the small seed and thinner seed coat than that of most other legumes (Hughes et al., 1986; Pratape et al., 2003). This is confirmed by the results obtained in study 1, showing that lentil fibre fractions obtained from dehulling were contaminated with large numbers of cotyledons. Another problem is its dark brown colour and bitter taste (Wang, 2005). In despite of negative effects, the benefit of using lentil seed coat cannot be ignored especially considering their health effects. It is well known that lentil seed coat is abundant in phenolic compounds and dietary fibres (Dalgetty & Baik, 2003; Oomah et al., 2011). The phenolic compounds are reported as excellent antioxidants and dietary fibres benefit gut health (Dueñas et al., 2006; Shahidi & Ambigaipalan, 2015). Several papers have been published regarding the use of lentil flours in various meat products to improve their cook yield and textural properties (Motamedi et al., 2015; Serdaroğlu et al., 2005; Shariati-Ievari et al., 2016). However, the use of lentil seed coat is rare and need further exploration.

In this study, two levels (1.25% and 2.5%) of HT lentil fibre fractions obtained in study 1 were used as ingredients in low-fat pork bologna. Their effects on the physicochemical, functional, textural and sensory properties were analyzed. Super Soy Fibre was used as a reference binder for comparison.

5.3 Materials and methods

The materials and methods for processing low-fat pork bologna with HT lentil fibre fractions were the same with study 2 except for the binders. In this study, the binders added to the bologna were HT lentil bran (22.58% protein, 14.70% starch and 49.16% TDF) and HT lentil fibre concentrate (23.43% protein, 23.29% starch and 37.99% TDF) at two levels (1.25% and 2.5%). The bolognas were formulated with the same non-meat ingredients as study 2. The reference in this study is a commercial product called Superb Soy Fibre (Archer Daniels Midland Company, Decatur, IL, USA) with 36.98% protein, 0.84% starch and 56.64% TDF. The

formulated bolognas were cooked following the same procedure with study 2. Any other properties were also analyzed with the same methods.

5.4 Results and discussion

5.4.1 Viscosity and pH

The viscosity and pH of processed raw meat batters formulated with HT lentil fibre fractions and Superb Soy Fibre are shown in Table 5-1. The temperature and pH of raw meat batters remained the same for all treatments. Adding binders increased the viscosity of meat batters. To be specific, the raw meat batter produced with Superb Soy Fibre showed significantly higher viscosity than the control formulation and increased addition level led to a higher viscosity value. Meat batters with 2.5% HT lentil fibre fractions showed significantly higher viscosity values compared with the control group. Meat batters treated with HT lentil fractions had comparable viscosity to the ones made with Superb Soy Fibre at the same addition level.

Table 5-1 Effect of binders on the viscosity, temperature and pH of raw meat batter (n=3)

Treatment	Viscosity (cP) $\times 10^4$	Temperature ($^{\circ}\text{C}$) ^{ns}	pH ^{ns}
Control	8.64 \pm 0.69 ^c	16.1 \pm 0.9	6.21 \pm 0.06
Superb Soy Fibre 1.25%	10.26 \pm 0.05 ^b	16.7 \pm 1.3	6.22 \pm 0.06
Superb Soy Fibre 2.5%	12.86 \pm 0.37 ^a	17.5 \pm 1.0	6.19 \pm 0.08
Lentil bran (HT) 1.25%	9.73 \pm 0.44 ^{bc}	16.5 \pm 0.4	6.21 \pm 0.05
Lentil bran (HT) 2.5%	11.99 \pm 0.29 ^a	17.3 \pm 0.2	6.19 \pm 0.06
Lentil fibre conc. (HT) 1.25%	9.93 \pm 0.34 ^{bc}	16.0 \pm 1.4	6.21 \pm 0.06
Lentil fibre conc. (HT) 2.5%	11.63 \pm 0.7 ^a	17.3 \pm 0.6	6.21 \pm 0.06

Values are presented as mean \pm standard deviation

^{a-c}: Means with different superscripts are significantly different ($p < 0.05$)

^{ns}: Means within the same column are not significantly different ($p > 0.05$)

fibre conc. = fibre concentrate

The increase in the viscosity of meat batters could be attributed to the moisture reduction and addition of binders with high water holding capacity. The increased viscosity of low-fat pork batter produced with soy protein concentrate and starch-based flours were also observed in other studies (Shand, 2000; Thushan Sanjeeva et al., 2010). However, Claus and Hunt (1991) reported that beef batters (10% fat) formulated with isolated soy protein and wheat starch had no difference in the viscosity ($p > 0.05$) with the control group.

5.4.2 Proximate analysis and pH

The proximate composition and pH value of the cooked bologna products with HT lentil fibre fractions and Superb Soy Fibre are shown in Table 5-2.

Table 5-2 Proximate composition and pH of cooked bologna products with binders (n=3)

Treatment	Moisture (%)	Protein (%) ^{ns}	Fat (%) ^{ns}	Ash (%) ^{ns}	pH ^{ns}
Control	75.75 ± 0.16 ^a	12.29 ± 0.20	8.88 ± 0.17	2.79 ± 0.04	6.42 ± 0.04
Superb Soy Fibre 1.25%	74.57 ± 0.43 ^b	12.72 ± 0.11	9.07 ± 0.59	2.81 ± 0.05	6.47 ± 0.04
Superb Soy Fibre 2.5%	73.11 ± 0.15 ^c	13.03 ± 0.22	9.28 ± 0.09	2.89 ± 0.03	6.48 ± 0.03
Lentil bran (HT) 1.25%	74.38 ± 0.40 ^b	12.60 ± 0.33	9.29 ± 0.45	2.83 ± 0.06	6.43 ± 0.03
Lentil bran (HT) 2.5%	73.36 ± 0.11 ^c	12.95 ± 0.39	9.12 ± 0.05	2.86 ± 0.03	6.41 ± 0.04
Lentil fibre conc. (HT) 1.25%	74.62 ± 0.32 ^b	12.50 ± 0.41	8.96 ± 0.18	2.84 ± 0.03	6.43 ± 0.03
Lentil fibre conc. (HT) 2.5%	73.34 ± 0.31 ^c	12.70 ± 0.18	9.14 ± 0.50	2.86 ± 0.05	6.42 ± 0.04

Values are presented as mean ± standard deviation

^{a-c}: Means with different superscripts are significantly different ($p < 0.05$)

^{ns}: Means within the same column are not significantly different ($p > 0.05$)

fibre conc. = fibre concentrate

Replacing the water with binder undoubtedly decreased the moisture content of cooked bologna products and increased binder addition level would enhance this reduction. Other than the moisture content, the protein, crude fat, ash and pH value of bologna products remained consistent for all treatments. The raw pork picnic had $19.42 \pm 0.10\%$ protein and $12.58 \pm 1.24\%$ fat. Again, the protein (12.29% to 13.03%) and fat content (8.88% to 9.29%) were slightly different from our original target value (11% and 10%, respectively) for the same reason mentioned in study 2. However, the protein values meet the Canadian regulation for bologna (9.5% meat protein and 11% total protein).

5.4.3 Colour measurement

The colour of the cooked bologna with different treatments is shown in Table 5-3.

Table 5-3 Effect of binders on the colour of cooked bologna products (n=3)

Treatment	CIE colour		
	L*	a* ^{ns}	b*
Control	70.04 ± 0.46 ^{ab}	16.26 ± 1.10	14.30 ± 0.40 ^d
Superb Soy Fibre 1.25%	70.55 ± 0.76 ^a	15.88 ± 1.14	15.08 ± 0.43 ^{bcd}
Superb Soy Fibre 2.5%	70.86 ± 1.01 ^a	15.83 ± 0.92	15.77 ± 0.39 ^{ab}
Lentil bran (HT) 1.25%	68.28 ± 0.87 ^{bcd}	14.61 ± 0.69	15.32 ± 0.13 ^{bc}
Lentil bran (HT) 2.5%	66.62 ± 0.58 ^d	14.35 ± 0.36	16.54 ± 0.27 ^a
Lentil fibre conc. (HT) 1.25%	68.94 ± 0.67 ^{abc}	15.12 ± 0.18	14.46 ± 0.21 ^{cd}
Lentil fibre conc. (HT) 2.5%	67.73 ± 0.57 ^{cd}	14.76 ± 0.09	15.68 ± 0.19 ^b

Values are presented as mean ± standard deviation

^{a-d}: Means with different superscripts are significantly different ($p < 0.05$)

^{ns}: Means within the same column are not significantly different ($p > 0.05$)

fibre conc. = fibre concentrate

Overall, binder addition affected the L* (lightness) and b* (yellowness) but not a* (redness) of bologna. Superb Soy Fibre did not significantly change the L* value. Different results were observed in HT lentil fibre fractions for their lower L* values compared with the control group. The statistically significant change in L* value only happened to bologna products with 2.5% HT lentil fibre fractions. No significant difference was found in a* value among all the treatments. In terms of b* value, all treatments had significantly higher values except for those with 1.25% Superb Soy Fibre and 1.25% HT lentil fibre concentrate which were similar to the control. The highest b* was obtained by adding 2.5% HT lentil bran and Superb Soy Fibre.

Increased b* value was also observed by including 2.5% and 5% chickpea and pea flour in the low-fat pork bologna (Thushan Sanjeeva et al., 2010). Higher values in L* and b* were reported by adding 3% and 7% lentil flours in beef patties without significant change in a* value (Baugreet et al., 2016). The lower L* value in our study could be explained by the dark color of lentil brans (data were presented in study 1). No changes in colour characteristics were reported by Pietrasik et al. (2012) when they used pea starch to produce restructured beef products. However, increased a* value was reported for the low-fat bologna with 4% pea starch earlier by the same group (Pietrasik & Janz, 2010). The different results could be due to the different binder types or different meat products. Decreased L* and a* values and increased b* value were also reported by Akesowan (2010) when they produced pork burger with increased level of soy

protein isolate. They suggested the colour change possibly resulted from the soy protein colour and diluted meat myoglobin. However, no significant change in the colour characteristics were observed by Claus and Hunt (1991) when they produced beef bologna with 2.0% isolated soy protein. The possible explanation for the different results could be the darker colour of beef than pork.

5.4.4 Cook loss, expressible moisture and purge loss

The cook loss, expressible moisture and purge loss of cooked bologna products with various binders are shown in Table 5-4.

Table 5-4 Effects of binders on the cook loss, expressible moisture and purge loss of cooked bologna products (n=3)

Treatment	Cook loss (%) ^{ns}	Expressible moisture (%)	Purge loss (%)	
			2 weeks	4 weeks
Control	0.49 ± 0.05	13.94 ± 0.54 ^a	3.03 ± 0.19 ^a	3.22 ± 0.30 ^a
Superb Soy Fiber 1.25%	0.49 ± 0.06	13.05 ± 0.92 ^{ab}	2.22 ± 0.14 ^b	2.65 ± 0.14 ^{abc}
Superb Soy Fiber 2.5%	0.50 ± 0.06	11.37 ± 0.80 ^b	1.50 ± 0.13 ^c	2.12 ± 0.21 ^c
Lentil bran (HT) 1.25%	0.45 ± 0.04	14.82 ± 0.77 ^a	2.38 ± 0.34 ^{ab}	2.84 ± 0.36 ^{ab}
Lentil bran (HT) 2.5%	0.45 ± 0.03	14.14 ± 0.87 ^a	2.02 ± 0.27 ^{bc}	2.58 ± 0.20 ^{abc}
Lentil fiber conc. (HT) 1.25%	0.48 ± 0.02	13.85 ± 0.87 ^a	2.27 ± 0.31 ^b	2.64 ± 0.19 ^{abc}
Lentil fiber conc. (HT) 2.5%	0.47 ± 0.04	13.00 ± 0.82 ^{ab}	2.16 ± 0.21 ^{bc}	2.30 ± 0.22 ^{bc}

Values are presented as mean ± standard deviation

^{a-c}: Means within a column with different letters are significantly different ($p < 0.05$)

^{ns}: Means within a column are not significantly different ($p > 0.05$)

fibre conc. = fibre concentrate

Cooked bologna had very low cook loss (less than 0.5%) without significant difference among all treatments. For expressible moisture, bologna product containing 2.5% Superb Soy Fibre showed the lowest value, which was significantly lower than the control sample. Other than that, no significant difference was found for all the other treatments. Regarding the purge loss, all the fibre products could significantly reduce the purge loss except for the bologna with 1.25% HT lentil bran. The lowest purge loss was obtained by adding 2.5% of all fibre products. Increased storage time did not significantly change the purge loss value for all the treatments.

One possible explanation for the improvement in water holding capacity of cooked bologna with Superb Soy Fibre and HT lentil fibre fractions could be the moisture reduction in the formulations with added fibres. Moreover, the binder itself could also contribute to the better water holding capacity with the combined effects of protein, starch and dietary fibre. To be specific, on the one hand, the binders themselves with high water holding capacity and oil absorption capacity could retain water and fat during cooking. On the other hand, the meat matrix structure, formed by meat protein and fat, could be enhanced by these binders through starch gelatinization, protein denaturation and gelation, in which way to entrap the water during cooking. Even though HT lentil fibre fractions did not affect the expressible moisture content, but they reduced the purge loss. Furthermore, the commercial product, Superb Soy Fibre, could improve both expressible moisture content and purge loss. All of these will contribute to the better quality of bologna products.

Pulse starch could functionally hold the extra water predominantly because the starch granule could swell by absorbing water during gelatinization under high temperature (Pietrasik et al., 2012; Ratnayake et al., 2002). Incorporating 5% starch based chickpea and pea flours into low-fat pork bologna products increased their cook yield and lowered the expressible moisture and purge loss (Thushan Sanjeeva et al., 2010). Pietrasik and Janz (2010) reported that incorporation of 4% pea flour and pea starch resulted in low-fat beef bologna products with higher cook yield and lower purge loss. Reduced cook loss was also found by this group when they included pea starch in restructured beef products with excessive water (Pietrasik et al., 2012). They suggested that the cook yield of meat products not only depended on the binder type, but also depended on the water addition level of meat products. Only few papers have reported the utilization of lentil flours in meat products. Motamedi et al. (2015) used 12% lentil flours to produce beef burger that had higher cook yield and less shrinkage. Consistent result was also obtained by Shariati-Ievari et al. (2016) when they prepared low-fat beef burger with 6% lentil flours and by Serdaroğlu et al. (2005) when they added 15% lentil flours into low-fat meatballs. Including lentil flours as a blended extender in the restructured chicken meat block also increased the cook yield (Malav et al., 2015). Soy protein has been used in meat products to increase cooking yield and water holding capacity. It also benefits the formation of protein matrix and fat stabilization during cooking (Su et al., 2000). It was reported that reduced-fat frankfurters produced with 2% soy protein showed higher cook yield (Su et al., 2000). They

suggested that the soy protein could immobilize the fat globules by forming a thick layer of protein membrane and also physically restrict the fat globules by the formation of protein matrix during cooking. Same results were also obtained by Akesowan (2010) by adding different concentration of soy protein isolate (1-3%) to pork burgers with increased cooking yield and decreased diameter reduction. In contrast, no significant changes in the cook loss and purge loss were found in the bologna product with 2% isolated soy protein (Claus & Hunt, 1991). Soy fibre was also reported to reduce the cook loss of pork bologna with increased fibre addition level (1-5%) (Cofrades et al., 2000).

5.4.5 Texture profile analysis

The textural profile of cooked bologna products with Super Soy Fibre and HT lentil fibre fractions are shown in Table 5-5.

Table 5-5 Effects of binders on textural properties of cooked bologna (n=3)

Treatment ¹	Textural profile analysis				
	Hardness (N)	Adhesiveness (N)	Cohesiveness	Springiness (%)	Chewiness (N mm)
Control	109.96 ± 2.60 ^{bc}	-0.51 ± 0.04 ^{ab}	0.49 ± 0.04 ^{ab}	80.28 ± 0.51 ^a	614.69 ± 40.75 ^{bc}
SSF 1.25%	125.16 ± 14.93 ^{ab}	-0.71 ± 0.04 ^{abc}	0.50 ± 0.01 ^{ab}	80.28 ± 0.48 ^a	698.18 ± 81.31 ^{ab}
SSF 2.5%	136.82 ± 1.92 ^a	-0.74 ± 0.15 ^{bc}	0.51 ± 0.02 ^a	78.88 ± 2.71 ^{ab}	773.97 ± 43.07 ^a
Lentil bran 1.25%	106.86 ± 4.16 ^{bc}	-0.73 ± 0.11 ^{bc}	0.46 ± 0.01 ^{ab}	77.10 ± 1.29 ^{ab}	527.99 ± 40.75 ^c
Lentil bran 2.5%	97.69 ± 8.06 ^c	-0.47 ± 0.06 ^a	0.33 ± 0.04 ^c	70.40 ± 2.01 ^c	323.77 ± 28.26 ^d
Lentil FC 1.25%	107.47 ± 12.14 ^{bc}	-0.58 ± 0.06 ^{abc}	0.50 ± 0.01 ^{ab}	78.18 ± 0.27 ^{ab}	588.32 ± 71.51 ^{bc}
Lentil FC 2.5%	117.78 ± 4.60 ^{abc}	-0.77 ± 0.08 ^c	0.43 ± 0.04 ^b	75.49 ± 1.54 ^b	536.46 ± 66.05 ^c

Values are presented as mean ± standard deviation

^{a-d}: Means with different superscripts are significantly different ($p < 0.05$)

SSF = Superb Soy Fibre

FC = fibre concentrate

¹: All lentil fibre fractions used were heat treated

Regarding the hardness, the highest value was obtained by bologna product with two levels of Superb Soy Fibre and 2.5% HT lentil fibre concentrate. Increased addition level did not significantly affect the hardness of bolognas. The hardness of all treatments was similar to the control group except for the one made with 2.5% Superb Soy Fibre with higher value. The

possible explanation for the harder texture obtained by adding 2.5% Superb Soy Fibre might be the stronger meat gel matrix formed with more soy protein. Usually, bologna with more added water has softer texture. However, this was not observed between the control group and bologna with any other treatments. Therefore, 2.5% more added water might not effectively enough to soften the texture. For the addition of HT lentil fractions, on the one hand, their starch and protein might have contributed to better gel formation and more consistent hardness because of less particulate nature and also swelling and gelatinization that integrates well with the texture of heat denatured muscle protein. On the other hand, the presence of coarse dietary fibre, mostly the high IDF of these pulse fibre sources might have affected negatively on the smooth texture of bologna. Therefore, the combined effects might be responsible for the unchanged hardness observed in this study. For adhesiveness, there was no significant difference among all the treatments except for 2.5% HT lentil fibre concentrate. Most treatments were not significantly different with the control group in cohesiveness and springiness except for the lower values obtained by adding 2.5% HT lentil fibre fractions. For chewiness, bologna with two levels of Superb Soy Fibre showed the highest value. Adding HT lentil fibre fractions lowered the chewiness but significant reduction only happened to the product with 2.5% HT lentil bran. Bologna with 2.5% HT lentil bran had the lowest cohesiveness, springiness and chewiness among all the treatments. This again can be related to the high IDF, low protein and starch that oppositely affect the continuous network of water-biopolymers (protein, starch and fat), and fracture parameters of the cooked bologna.

Texture profile analysis was an objective method to measure the difference in the textural properties of bologna products with different binders. Overall, adding Superb Soy Fibre at two levels could improve or maintain all the textural properties. For HT lentil fibre fractions, addition level at 1.25% did not induce significant change in the texture compared with the control group while 2.5% addition level could impair some of the properties. Many papers have reported the changes in the textural profile of meat products with pulse starch and soy protein. Beef products restructured with pea starch showed harder texture than the control group (Pietrasik et al., 2012). Consistent results were found in the raw beef burger with 12% lentil flours (Motamedi et al., 2015) and in the restructured chick meat block with extender including 5% hydrated lentil flours (1:1, w/w) (Malav et al., 2015). No difference was found in the hardness and cohesiveness for low-fat beef bologna products with 4% pea flour, but significant increase in these properties was

found in the ones with 4% pea starch (Pietrasik & Janz, 2010), indicating the effect of higher starch content. The increase in the hardness and cohesiveness were also reported by Thushan Sanjeeva et al. (2010) when they utilized 5% chickpea flours to produce low-fat pork bologna. In contrast, the reduction in the hardness and cohesiveness was found in the beef patties with 3% and 7% lentil flours (Baugreet et al., 2016). They suggested that this softer texture could result from the rapid hydration of fine lentil flours particles with low density. For the use of the soy protein, it was reported that including soy protein isolate in the range of 0.5% to 2% would not significantly change the hardness of pork burger while the hardness would decrease significantly at 3% addition level. The reduction possibly resulted from the extra water from hydrated soy protein isolate (Akesowan, 2010). The different result was observed on the bologna with 2% isolated soy protein with higher values in the hardness and no change in the cohesiveness (Claus & Hunt, 1991). These contradictory results may be due to the different type of meat products and the procedure of adding soy protein. The utilization of soy fibre in the pork bologna has also been reported. Increased addition level of soy fibre increased the hardness but decreased the cohesiveness of pork bologna (Cofrades et al., 2000). Our results show that adding Superb Soy Fibre resulted in bologna with harder texture. Including HT lentil fibre concentrate did not significantly change most textural properties, but the addition of 2.5% HT lentil bran produced bologna with lower values in cohesiveness, springiness and chewiness.

5.4.6 Sensory evaluation by trained panelists

The sensory evaluation was carried out with 14 trained panelists and the result is shown in Table 5-6.

Table 5-6 Effects of binders on the sensory properties of cooked bologna evaluated by trained panelists (n=3)

Treatment	Sensory properties						
	Firmness	Cohesiveness	Juiciness	Graininess	Overall flavor intensity ^{ns}	Foreign flavor	Overall acceptability
Control	5.3 ± 0.3 ^{bc}	5.3 ± 0.3 ^b	5.8 ± 0.1 ^a	1.2 ± 0.1 ^d	5.4 ± 0.2	7.5 ± 0.2 ^a	6.2 ± 0.3 ^a
Superb Soy Fibre 1.25%	5.8 ± 0.3 ^{ab}	5.6 ± 0.0 ^{ab}	5.4 ± 0.1 ^{ab}	1.7 ± 0.3 ^{bcd}	5.3 ± 0.0	7.1 ± 0.2 ^a	5.9 ± 0.1 ^{ab}
Superb Soy Fibre 2.5%	6.2 ± 0.1 ^a	5.8 ± 0.0 ^a	4.8 ± 0.2 ^c	2.0 ± 0.2 ^{bc}	5.4 ± 0.3	6.1 ± 0.1 ^b	5.5 ± 0.4 ^{ab}
Lentil bran (HT) 1.25%	5.1 ± 0.1 ^{cd}	5.1 ± 0.1 ^b	5.4 ± 0.1 ^{ab}	2.1 ± 0.2 ^{bc}	5.4 ± 0.3	5.8 ± 0.3 ^{bc}	5.3 ± 0.3 ^{bc}
Lentil bran (HT) 2.5%	4.6 ± 0.1 ^d	4.5 ± 0.1 ^c	4.7 ± 0.2 ^c	2.7 ± 0.2 ^a	5.6 ± 0.3	5.4 ± 0.1 ^c	4.6 ± 0.3 ^c
Lentil fibre conc. (HT) 1.25%	5.3 ± 0.2 ^{bc}	5.5 ± 0.2 ^{ab}	5.6 ± 0.2 ^{ab}	1.5 ± 0.2 ^{cd}	5.3 ± 0.1	7.0 ± 0.3 ^a	5.8 ± 0.2 ^{ab}
Lentil fibre conc. (HT) 2.5%	5.1 ± 0.3 ^c	5.1 ± 0.2 ^b	5.0 ± 0.3 ^{bc}	2.1 ± 0.2 ^b	5.3 ± 0.5	6.2 ± 0.3 ^b	5.1 ± 0.4 ^{bc}

Values are presented as mean ± standard deviation

^{a-d}: Means with different superscripts are significantly different ($p < 0.05$)

^{ns}: Means in the same column (different treatments) are not significantly different ($p > 0.05$)

fibre conc. = fibre concentrate

Firmness: 8 = Extremely firm, 1 = Extremely soft

Cohesiveness: 8 = Extremely cohesive, 1 = Extremely brittle

Juiciness: 8 = Extremely juicy, 1 = Extremely dry

Graininess: 6 = Extremely grainy, 1 = Not detectable.

Overall flavor intensity: 8 = Extremely intense, 1 = Extremely bland

Foreign flavor: 8 = No foreign flavor, 1 = Extremely intense foreign flavor

Overall acceptability: 8 = Like extremely, 1 = Dislike extremely

For the firmness, the highest score was obtained by bologna with 2.5% Superb Soy Fibre and the lowest score was given to the product with 2.5% HT lentil bran. Increasing the binder addition did not make significant differences. It could be seen that bologna products with Superb Soy Fibre were firmer than the ones with HT lentil fibre fractions at the same addition level. However, except for 2.5% Superb Soy Fibre (highest score) and 2.5% HT lentil bran (lowest score), no significant difference in the firmness were found by the trained panelists when comparing the control group with any other treatments. The results basically corresponded with the result of hardness obtained by instrumental measurement.

Regarding cohesiveness, the trend was similar with the firmness. The highest and lowest scores were obtained by bologna produced with 2.5% Superb Soy Fibre and 2.5% HT lentil bran, respectively. Any other treatments had no statistically significant difference with the control group. The results were also similar with the results obtained with Textural Profile Analysis.

In terms of juiciness, the control group showed the highest score but not different from the one with 1.25% binders. Adding 2.5% of all binders resulted in significantly lower values than the control group. No significant difference was found in the juiciness of all binders at the same addition level. The possible explanation was the gradually reduced moisture content along with increased amount of binders.

Considering the graininess, adding binders increased the score for graininess and higher addition level would enhance this trend. The bologna product with 2.5% HT lentil bran showed the highest score. Except for bologna with 1.25% Superb Soy Fibre and HT lentil fibre concentrate, the graininess of all the other treatments was significantly higher than the control group which illustrated that the panelists could recognize the presence of binder particles when they tasted the bologna.

The overall flavor intensity of cooked bologna products would not be affected by including different binders which was reflected by the similar scores evaluated by the panelists.

The foreign flavor is an important consideration when incorporating novel binders into bologna products because they could bring undesirable flavor. In Table 5-6, it could be seen that adding 2.5% binders would significantly lower the scores of all treatments compared with the control group. However, the scores of samples with 1.25% Superb Soy Fibre and 1.25% HT lentil fibre concentrate were not significantly different with the control group. The lowest score was obtained by bologna with 2.5% HT lentil bran.

The overall acceptability was evaluated by the panelists to give a tentative idea if the bologna formulations with binders have the potential to be developed into the commercial products. As the result showed, even though including binders would decrease the scores of overall acceptability, all of the bologna products were given the scores higher than 4.5. This means that they are acceptable to the panelists. No significant difference was found among the control group and bologna made with two levels of Superb Soy Fibre and 1.25% HT lentil fibre concentrate.

Overall, using the Superb Soy Fibre as binders in bologna products would improve some of their properties such as firmness, cohesiveness and maintain the overall flavor intensity. For the HT lentil fibre fractions, incorporation of HT lentil fibre concentrate at two levels and 1.25% HT lentil bran would not significantly change the firmness, cohesiveness and overall flavor intensity. Even though all of these binders could be recognized by the trained panelists with lower juiciness, increased graininess and more foreign flavor, these products were still acceptable and had the potential to be developed into commercial products. From the perspective of human nutrition, by serving these products (100 gram/serving), up to 1.4 gram total dietary fibre will be delivered to the human body.

Reduction in juiciness by adding starch-based binder, such as modified corn starch and pea starch, was found by Pietrasik et al. (2012). They suggested that this could result from the competition between starch and mouth muscle protein for the free available water. Their results also showed that the consumers' acceptability about the colour, flavor, texture and their overall acceptability of the beef products would not be affected significantly by starch addition. Different results were found in the sensory evaluation when using pea flour and pea starch to produce low-fat beef bologna. To be specific, adding 4% pea flour decreased the consumer's acceptance score for flavor and overall acceptability while for bologna with 4% pea starch, these properties remained similar with the control group (Pietrasik & Janz, 2010). The 5% addition of chickpea flour produced low-fat pork bologna with lower juiciness, firmer texture, and weak foreign flavor evaluated by semi-trained panelists. Increasing the lentil flour addition level (4%, 8% and 12%) in beef burgers led to a lower score in the desirability of panelists for the colour, flavor, texture and overall acceptability compared with control group (Motamedi et al., 2015). Restructured chicken meat blocks with 5% hydrated lentil flours had comparable scores in the overall acceptability to the control group (Malav et al., 2015). Low-fat beef burger with 6% lentil

flours received higher acceptability scores than the control group based on the consumer test (Shariati-Ievvari et al., 2016). Low-fat meat balls with 10% lentil flours had high scores in the overall palatability (Serdaroğlu et al., 2005). The pork burger produced with 2% hydrated soy protein isolate showed no significant difference in the scores of colour, juiciness, flavor and overall liking and higher score for texture compared with control group (Akesowan, 2010). However, they also indicated that the beany flavor could be a potential problem for its utilization in the meat product with significantly decreased score of flavor in the product at 3% addition level. Claus and Hunt (1991) reported that bologna with 2% isolated soy protein showed higher scores in firmness and cohesiveness, lower scores in juiciness and not significantly different score in graininess compared with control group.

5.4.7 Correlation coefficients analysis

The results of Pearson correlation analysis were shown in Table 5-7. The expressible moisture was negatively correlated with hardness ($r = -0.70, p < 0.01$). In textural properties, TPA hardness had strong positive relation with chewiness ($r = 0.85, p < 0.01$). TPA cohesiveness were positively correlated with springiness and chewiness ($r = 0.94$ and 0.86 , respectively, $p < 0.01$). Springiness and chewiness has significant positive correlations ($r = 0.83, p < 0.01$). For the sensory evaluation, the firmness and cohesiveness were positively correlated with the TPA hardness and cohesiveness ($r = 0.75$ and 0.79 , respectively, $p < 0.01$). Significant positive correlation was found between firmness and cohesiveness ($r = 0.92, p < 0.01$). Juiciness was negatively correlated with graininess ($r = -0.78, p < 0.01$). Significant positive correlations were found between overall acceptability, and juiciness and foreign flavor ($r = 0.74$ and 0.85 , respectively, $p < 0.01$) and negative correlation was found between overall acceptability and graininess ($r = -0.76, p < 0.01$).

Table 5-7 Correlation coefficients among data of some functional properties, instrumental textural parameters and sensory parameters of low-fat pork bologna with HT Lentil fibre fractions and Superb Soy Fibre (n=21)

	2	3	4	5	6	7	8	9	10	11	12	13
Functional property												
1. Expressible moisture	-0.70**	0.26	-0.23	-0.20	-0.56**	-0.72**	-0.60**	0.33	-0.01	0.14	0.01	0.02
Textural profile analysis (TPA)												
2. Hardness	1	-0.59**	0.47*	0.45*	0.85**	0.75**	0.69**	-0.13	-0.10	-0.09	0.11	0.28
3. Adhesiveness		1	-0.36	-0.41	-0.51*	-0.39	-0.40	0.20	-0.02	0.13	0.17	0.06
4. Cohesiveness			1	0.94**	0.86**	0.69**	0.79**	0.54*	-0.77**	-0.41	0.61**	0.70**
5. Springiness				1	0.83**	0.65**	0.75**	0.55*	-0.83**	-0.35	0.69**	0.69**
6. Chewiness					1	0.84**	0.87**	0.24	-0.53*	-0.29	0.45*	0.58**
Sensory evaluation												
7. Firmness						1	0.92**	0.06	-0.40	-0.15	0.36	0.49*
8. Cohesiveness							1	0.27	-0.56**	-0.30	0.49*	0.57**
9. Juiciness								1	-0.78**	-0.23	0.74**	0.74**
10. Graininess									1	0.36	-0.86**	-0.76**
11. Overall flavor intensity										1	-0.15	0.08
12. Foreign flavor											1	0.85**
13. Overall acceptability												1

** = Correlation is significant at the 0.01 level (2-tailed)

* = Correlation is significant at the 0.05 level (2-tailed)

5.5 Conclusions

Two levels of HT lentil fibre fractions were utilized as binders in the production of low-fat pork bologna. The results showed that adding these fibre products would increase the viscosity of raw meat batters. After cooking, all bologna products showed consistent values in protein, fat and ash content except for the lower moisture content observed by bologna with binders. HT lentil fibre fractions lowered the lightness and increased the yellowness of bologna colour without affecting their redness significantly. Incorporation of fibre products could reduce the purge loss but their cook loss and expressible moisture content showed no significant difference. For the textural profile analysis, HT lentil fibre fractions did not bring any changes in the hardness compared to the control group. However, 2.5% HT lentil bran significantly decreased the cohesiveness compared with the control group. For the sensory evaluation, fourteen panelists perceived most bologna products as similarly firm and cohesive as the control group. However, bologna with 2.5% HT lentil bran got the lowest score in firmness and cohesiveness among all the products. Even though the texture of most products were similar with each other, the panelists still could recognize the addition of fibre products reflected by the lower scores in juiciness, foreign flavor and increased score in graininess. All the products were acceptable to the panelists, indicating that they all had the potential to be developed into commercial products.

According to the results, we presumed that the changes in the texture or functional performance of bologna by adding HT lentil fibre fraction were attributed to both starch and dietary fibre levels of the fibre source. The better results obtained from HT lentil fibre concentrate than HT lentil bran might be due to its higher starch content. One drawback of adding HT lentil fibre fractions was the presence of dark seed coat particles in the homogeneous bologna matrix which could be perceived by panelists. This was the main reason why we changed the fluorescent light to the red light when we carried out the sensory evaluation to mask the bologna colour. By doing this, the panelists would put more attention on the texture and flavor rather than the colour. However, if the products will be developed into the commercial ones, this problem could not be avoided. Another negative effect brought by HT lentil fibre fractions is their large fibre particles rich in IDF which might have increased the graininess of bologna product. Therefore, further milling into smaller particle may be a suitable recommendation.

6. GENERAL DISCUSSION

The overall objective of this project was to investigate the functional properties of fibre fractions processed from seed coats of yellow pea and red lentil, and their potential application in low-fat pork products. Pea and lentil are two important pulse crops in Saskatchewan and leading exports to the worldwide pulse market (Saskatchewan Pulse Growers, 2016). Their seed coats, the byproducts of pulse processing, are great sources of dietary fibre and underestimated for their potential uses as novel food ingredients. To make a better use of these byproducts, the seed coat fractions were isolated from yellow pea and red lentils by dehulling and their potential use in the low-fat pork bologna was explored in this project.

In the first part of the project, sieving was employed to separate each seed coat fraction into two portions, namely bran and fibre concentrate. All the fibre fractions were later treated with lab-scale hydrothermal treatment and milled into fine flours. Their physical, chemical and functional characteristics were investigated. Two commercial fibre products Best Pea Fibre and Superb Soy Fibre were also included as reference samples for comparison. For the physical properties, lentil fibre fractions showed a darker brown colour while pea fibre fractions had lighter yellow colour. Dehulling could separate intact seed coats of yellow pea with visible round shape but much smaller pieces and broken seed coats were found in red lentils. Besides, the presence of red cotyledons in the lentil fibre fractions indicated that the fibre source was contaminated with cotyledons in a considerable amount. Red lentil seeds were relatively flat and small compared with yellow pea seeds which were round and bigger in size. Therefore, dehulling alone was not effective to isolate pure seed coats from red lentil. Additional treatment such as multiple rounds of air classification with appropriate sieving was highly recommended to obtain seed coat fraction with higher purity. After milling, the lentil fibre fractions had much finer particles than pea fibre fractions. The possible explanation was that cotyledons were more easily broken into fine flours than seed coats. Both fibre fractions showed much larger particle size than two commercial products. The results of chemical analyses confirmed the cotyledon contamination in lentil fibre fractions due to the presence of large protein and starch portions (21.16 – 23.18% and 14.75 – 17.44%, respectively) with concentrated dietary fibre content

(46.60 – 50.04%). However, pea fibre fractions were mainly composed of dietary fibre (79.27 – 88.79%), indicating that dehulling could separate pea fibre with high purity. The Best Pea Fibre was a fibre based product (80.79% TDF) and Superb Soy Fibre was protein and fibre based product (36.98% protein and 56.64% TDF). All the fibre products predominantly consisted of IDF rather than SDF. The lentil fibre fractions had much higher total phenolic content than pea fibre fractions possibly because of their more coloured seed coat (Campos-Vega et al., 2010). Sieving could further purify the pea fibre fractions because the pea fibre concentrate showed higher TDF, less protein and starch content than pea bran. However, it did not work for lentil fibre fractions because both bran and fibre concentrate got contaminated by cotyledons.

Lipoxygenase is a deleterious enzyme responsible for the production of off-flavor in food products. One interesting thing we found in this project was that pea fibre fractions with much less protein content in comparison to lentil fibre fractions had significantly higher LOX activity than that of lentil fibre fractions. The possible explanation was that the presence of large amounts of phenolic compounds in seed coats of red lentils helped to inhibit the enzyme activity through non-covalent interactions with enzyme protein (Kubicka & Troszyńska, 2003). Hydrothermal treatment is a common procedure used in food industry to reduce moisture content, inactivate enzyme and reduce microorganisms. The lab-scale hydrothermal treatment (steam treatment at 180 °C for 10 min) employed in this project effectively reduced the moisture content of all fibre products but it did not bring any effects on the lipoxygenase activity. Therefore, if LOX inactivation is an outcome expected in the treatment, an elevated temperature or prolonged heat treatment should be applied to these fibre products before using in food products. One more unexpected result was that the hydrothermally treated lentil fibre concentrate had lower TDF and total phenolic content and higher protein and starch content than the non-treated ones. It was presumed that part of the seed coats may have been removed during the treatment. To keep the quality of final fibre products consistent, the ingredient supplier should have a comprehensive understanding on the effect of biological, chemical and physical properties of the fibre source during the treatment.

Concerning the functional properties, the protein and fibre based products showed better water holding capacity and oil absorption capacity than the starch based products. Superb Soy Fibre, Best Pea Fibre and pea fibre fractions showed higher water holding capacity than lentil fibre fractions. Compared with native starch, dietary fibre and protein might have better ability to

bind or hold water because of the presence of hydrophilic groups (Ahmed et al., 2016; Kaur & Singh, 2005; Shand, 2000; Wang & Toews, 2011). The highest oil absorption capacity was observed in Superb Soy Fibre, followed by Best Pea Fibre and then pea fibre fractions. The protein based ingredients are excellent in binding oil due to their hydrophobic side chains (Ahmed et al., 2016; Sosulski & Youngs, 1979). For dietary fibre based ingredients, their physical structure reflected by particle size and surface characteristics is more important in determining their oil absorption capacity (Ahmed et al., 2016; Ma & Mu, 2016b). In this project, the chemical composition of pea bran and Best Pea Fibre were very similar and their only difference was the different particle size. The smaller size of Best Pea Fibre could have exposed more surface area or porosity to interact and bind the oil, leading to its higher value than the pea bran. It was also reported that certain dietary fibre constituents contributed to the better oil absorption capacity (Sosulski & Cadden, 1982). This could be the reason for the higher oil absorption capacity obtained by pea fibre concentrate than pea bran. Almost all the fibre products showed higher values in hot absorption than their corresponding water holding capacity because of the swelling capacity of dietary fibre and starch (Agboola et al., 2010; Fleury & Lahaye, 1991). Only Superb Soy Fibre showed the opposite trend. It was hypothesized that at high temperature (75 °C), the soy protein partially denatured, and more exposure of interior hydrophobic groups lowered its ability to bind the water. In terms of pasting properties, lentil fibre fractions showed a pasting curve of starch based ingredients with lower peak and final viscosity than the native lentil starch because of the dilution with protein and dietary fibre (Joshi et al., 2013). Protein and dietary fibre based ingredients only showed gradual increases in the viscosity. When the holding temperature was changed from 95 °C (standard method temperature) to 75 °C (bologna cooking temperature), the final viscosity of all fibre products significantly decreased possibly because of the lower swelling capacity resulting from lower heat temperature. Based on these results, it could be summarized that the functional properties of fibre products were mainly determined by their chemical composition and physical properties.

Low-fat meat products are attractive to the health conscious consumers because of less inclusion amounts of animal fat than regular-fat products. However, their poor texture and water holding capacity are main concerns preventing them being successful products on the market (Keeton, 1994). In study two, two levels (1.25% and 2.5%) of Best Pea Fibre and HT pea fibre fractions were used as binders and incorporated into low-fat pork bologna by partially replacing

the water. The low-fat bologna was formulated to contain 11% protein and 10% fat to meet Canadian regulation (minimum 9.5% meat protein and 11% total protein in the cooked product). For the functional properties, all the bologna had very low cook loss (less than 1%) and including HT pea fibre fractions effectively reduced the purge loss. Lower purge loss illustrated that fibre rich products could benefit low-fat bologna products by binding more water during the storage. This was supported by the results of study 1, showing that HT pea fibre fractions had high water holding capacity. However, adding HT pea fibre fractions significantly increased the expressible moisture content. The possible explanation was that even though the pea fibre fractions themselves could bind more water, they did not contribute to forming good bologna structure. Therefore, part of the water entrapped in the emulsion system was lost under centrifugation force and led to the higher expressible moisture. Even though adding Best Pea Fibre could lower both expressible moisture content and purge loss, but this reduction is not significantly different with the control group. Higher addition level might be necessary to achieve better results.

Considering the textural characteristics, the results showed that Best Pea Fibre improved the low-fat bologna products by making their texture firmer. On the contrary, adding the HT pea fibre fractions impaired their structure. Consistent results were also obtained by the sensory evaluation conducted with fourteen trained panelists. Even though the pea fibre fractions had similar chemical composition with Best Pea Fibre (results shown in study 1), their effects on the texture of low-fat bologna were quite different. It was assumed that the larger particle sizes of HT pea fibre fractions than Best Pea Fibre might be responsible for their unfavorable effects. Their large particle size could have prevented the thorough mixture and interaction with other constituents in bologna emulsion system. Additionally, the panelists evaluated the bologna products with all binders less juicy, grainier and more foreign flavor. The juiciest product was the control formulation with the highest moisture content. Higher scores in graininess were found in bologna with HT pea fibre fractions than the ones with Best Pea Fibre, indicating that binders with larger particles produced more grainy products. The most foreign flavor was found in bologna with 2.5% HT pea bran. The possible reason was that HT pea bran had the most off flavor resulting from its relatively higher fat content (0.63%), compared with pea fibre concentrate (0.35%), and lipoxygenase activity, compared with Best Pea Fibre (Iassonova et al., 2009). The Best Pea Fibre, with positive effects on both functional and textural properties of

low-fat bologna, produced acceptable products to panelists and provided additional 2% dietary fibres. Regardless of negative effects on texture, bologna products with 1.25% HT pea fibre fractions were acceptable to panelists and worth further improvement.

Superb Soy Fibre and HT lentil fibre fractions were also utilized to produce low-fat bologna products using the same formula and procedure as study 2. Addition of these binders separately showed a significant reduction in the purge loss and increase in the binder addition level led to further lower values. In study 1, the lentil fibre fractions showed low water holding capacity and oil absorption capacity because of the presence of more starch. However, their water holding capacity would be significantly improved upon heating due to the starch gelatinization (reflected by their much higher hot absorption values than water holding capacity, and pasting properties under bologna cooking condition). The swelling of starch granules helped to absorb more water and contributed to better water holding capacity in bologna (Pietrasik et al., 2012). In addition, the Superb Soy Fibre reduced the expressible moisture content of low-fat bologna but HT lentil fibre fractions brought no effects. The unchanged values possibly resulted from the combined effects of both dietary fibre and starch on bologna texture.

According to textural profile analysis, low-fat bologna with Superb Soy Fibre had firmer texture but no significant changes were found in the ones with lentil fibre fractions. Same results were also obtained by the panelists recruited for sensory evaluation. The lowest values for firmness and cohesiveness were found in bologna with 2.5% HT lentil bran. However, the texture of bologna with 2.5% HT lentil fibre concentrate was not significantly different with the control group. The possible explanation was its higher starch content than HT lentil bran. The swollen starch granule could be embedded in the protein gel matrix formed during cooking and created more compact structure (Carballo et al., 1995). The highest firmness and cohesiveness found in bologna with Superb Soy Fibre could be attributed to the presence of more protein. The protein contributed to the better texture by stabilizing the emulsion system as emulsifier and also by forming gel during cooking (Su et al., 2000). Its finer particles could also have achieved better mixture and interaction between the dietary fibre and other constituents in the bologna emulsion system. For the other sensory properties, bologna with added binders showed similar results as study 2 with less juiciness, higher graininess and more foreign flavor. However, these negative effects were much less than those brought by including HT pea fibre fractions. One possible reason was that lentil fibre fractions were finer than the pea fibre fractions, resulting in

better mixture and interaction between different constituents. Another reason was that the lipooxygenase activities found in lentil fibre fractions were much lower than the pea fibre fractions. Therefore, less off flavor would have been produced and less foreign flavor were found in finished bologna products. Last but not least, the presence of more protein and starch in lentil fibre fractions might have brought positive effects on the bologna structure than the fibre based pea fibre fractions, leading to their different results on the expressible moisture content and textural characteristics. All the products with binders were acceptable to the panelists with more fibre included in the finished bologna products.

In summary, the functional properties of fibre products are not only determined by their chemical composition, but also probably affected by their physical characteristics such as particle size and surface characteristics. These differences would ultimately influence their performance when incorporated into low-fat bologna products. Another important factor should be taken into consideration when applying these fibre products in food products is the lipooxygenase activity. Heat treatment sufficient to inactivate lipooxygenase should be applied to prevent production of off-flavor and potential negative consequences resulting from lipid oxidation products.

7. OVERALL CONCLUSION

The ultimate goal of this project is to analyze the physicochemical and functional properties of fibre fractions from yellow pea and red lentil, and their application in low-fat pork bologna. In this project, two commercial products Best Pea Fibre and Superb Soy Fibre were used as reference for comparison. The results showed that dehulling and subsequent sieving separated fibre fractions with quite different chemical composition, which exerted significant effects on their functional properties. To be specific, pea fibre fractions were composed dominantly of dietary fibre while lentil fibre fractions contained approximately 50% dietary fibre and fair amount of protein and starch because of the cotyledon contamination during dehulling. In addition, Best Pea Fibre had similar chemical composition with pea bran while Superb Soy Fibre showed different chemical characteristics with protein and dietary fibre as the main constituents. The ingredients with higher content in dietary fibre and protein, such as pea fibre fractions, Best Pea Fibre and Superb Soy Fibre, showed better water holding capacity and oil absorption capacity than the ingredients rich in starch, namely lentil fibre fractions. At higher temperature, dietary fibre and starch will swell and absorb more water while protein will denature. This led to the different results of fibre products in hot absorption. Additionally, the particle size of fibre based ingredients might be an important factor affecting their functionality, especially for oil absorption capacity. Even though more protein was present in lentil fibre fractions, the lipoxigenase activity of pea fibre fractions were still significantly higher than the lentil fibre fractions. This possibly could be explained by much higher total phenolics content found in lentil fibre fractions which inhibited the enzyme activity. Lab-scale hydrothermal treatment was used to make the fibre fractions food grade. However, it did not effectively inactivate the lipoxigenase activity and surprisingly removed part of the seed coats from the lentil fibre concentrate. Modification of this treatment should be considered in future study.

Two levels of HT pea and lentil fibre fractions were used as binders to produce low-fat pork bologna, as well as two commercial products as reference. According to the results, adding HT pea and lentil fibre fractions could significantly increase the meat batter viscosity and reduce the

the purge loss. Possible explanation was the high water holding capacity of dietary fibre and protein, and starch swelling during cooking. Adding fibre fractions also affected the colour characteristics of bologna products. Especially, bologna made with HT lentil fibre fractions showed a darker colour. This could be a potential problem for their wide application. For the textural properties, adding HT pea fibre fractions reduced the hardness and cohesiveness of cooked bologna while HT lentil fibre fractions did not brought significant effects on these two properties. The changes in the bologna structure might result from their different chemical composition. Also, it was suggested that reducing the particle size of HT pea fibre fractions might be helpful for obtaining bologna products with better texture. The different results in the textural profile might be the reason for their different effects on the expressible moisture content. According to the results of sensory evaluation conducted with fourteen trained panelists, it could be concluded that adding all fibre products brought foreign flavor and made the bologna grainier and less juicy. The foreign flavor was especially recognizable in bologna with HT pea fibre fractions presumably because of the lipid oxidation induced by the lipoxygenase. Therefore, harsher heat treatment should be employed to inactivate this enzyme before their use in food products. Also, the juiciness of the bologna should be increased, possibly by including more water. In spite of these negative effects, some of the products were still acceptable to the panelists including bologna with two levels of Best Pea Fibre, Superb Soy Fibre and HT lentil fibre fractions, and 1.25% HT pea fibre fractions. This could be a clear evidence indicating that these products have the potential to be developed into commercial products and serves additional 1-2% dietary fibre to the consumers of processed low-fat meat products. Information on product acceptability should be confirmed with a large group of consumers.

8. REFERENCES

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Appendix A. Score card for sensory evaluation

Name:..... Date:

Instructions: Please evaluate the samples in the order that the scorecards are arranged. For each characteristic, **circle** the descriptor that best describes your impression. Please take a drink of water and unsalted crackers before and between samples. Feel free to provide any comments as well.

Sample #:

Booth #:.....

Panelist #:.....

Scores	8	7	6	5	4	3	2	1
Firmness	Extremely firm	Very firm	Moderately firm	Slightly firm	Slightly soft	Moderately soft	Very soft	Extremely soft
Cohesiveness	Extremely cohesive	Very cohesive	Moderately cohesive	Slightly cohesive	Slightly brittle	Moderately brittle	Very brittle	Extremely brittle
Juiciness	Extremely juicy	Very juicy	Moderately juicy	Slightly juicy	Slightly dry	Moderately dry	Very dry	Extremely dry
	6	5	4	3	2	1		
Graininess	Extremely grainy	Very grainy	Moderately grainy	Slightly grainy	Very Slightly grainy	Not detectable		
	8	7	6	5	4	3	2	1
Overall Flavor Intensity	Extremely intense	Very intense	Moderately intense	Slightly intense	Slightly bland	Moderately bland	Very bland	Extremely bland
Foreign Flavor	No foreign flavour	Very weak	Moderately weak	Slightly weak	Slightly intense	Moderately intense	Very intense	Extremely intense foreign flavor
Overall Acceptability	Like extremely	Like very much	Like moderately	Like slightly	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely

Additional Comments:

Appendix B. Terminology used for sensory evaluation

Firmness: the force required to bite through the sample with the incisors/front teeth;

Cohesiveness: the extent to which the sample was deformed between the teeth before it ruptures/breaks down; Degree to which sample deforms (rather than ruptures)

Juiciness: the amount of fluid in the mouth during the first several chews; amount of juice released as teeth apply pressure;

Graininess: the presence of small particles after chewing;

Overall Flavor Intensity: the amount of typical bologna seasoning and meat flavour present in the mouth after complete mastication

Foreign Flavor: the amount of any atypical or off-flavors present in the mouth after complete mastication (if any present, please describe or identify the flavor in comments section)

Overall Acceptability: degree of acceptability of product